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Filipovic et al.

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[45] **Date of Patent: *Nov. 23, 1999**

[54] **COUPLED MULTI-SEGMENT HELICAL ANTENNA**

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[73] Assignee: **Qualcomm Incorporated**, San Diego, Calif.

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[22] Filed: **Apr. 30, 1996**

[51] **Int. Cl.**[6] **H01Q 1/36**; H01Q 1/24

[52] **U.S. Cl.** **343/895**; 343/702

[58] **Field of Search** 343/895, 702, 343/850, 908, 796, 853

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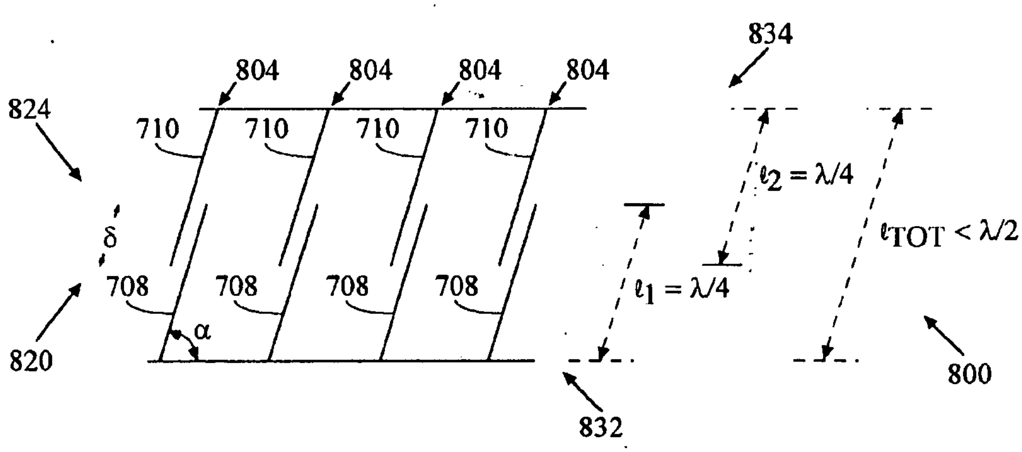
Primary Examiner—Hoanganh Le

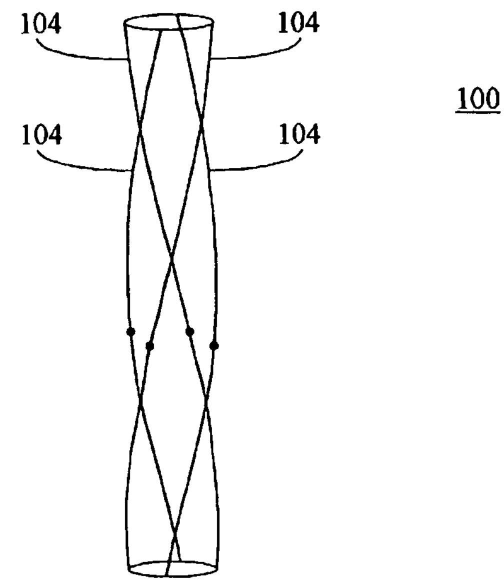
Attorney, Agent, or Firm—Russell B. Miller; Gregory D. Ogrod

[57] **ABSTRACT**

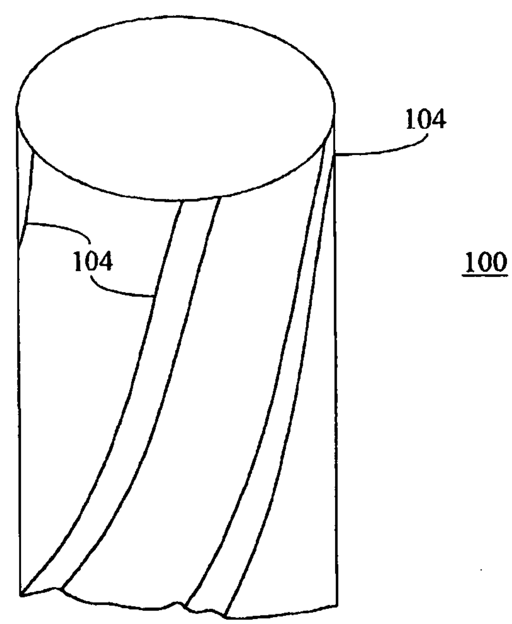
A coupled multi-segment helical antenna is provided having a length that is shorter than otherwise obtainable for a conventional half-wavelength antenna. The coupled multi-segment helical antenna includes radiator portion having a plurality of helically wound radiators extending from one end of the radiator portion to the other end of the radiator portion. Each radiator is made up of a set of two or more segments. A first segment extends in a helical fashion from the first end of the radiator portion toward the second end of the radiator portion. The second segment extends in a helical fashion from the second end of the radiator portion toward the first end of the radiator portion, wherein a portion of the first radiator segment is in proximity with a portion of the second radiator segment such that the first and second radiator segments are electromagnetically coupled to one another.

29 Claims, 13 Drawing Sheets





PRIOR ART
FIG. 1A



PRIOR ART
FIG. 1B

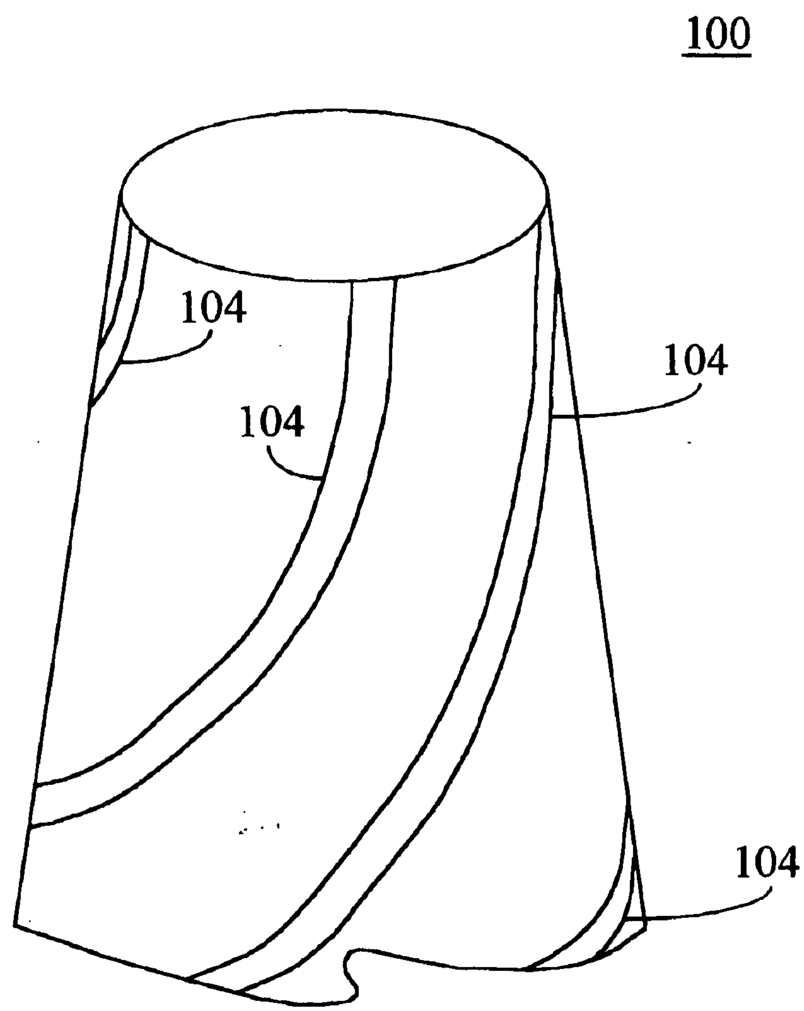


FIG. 1C

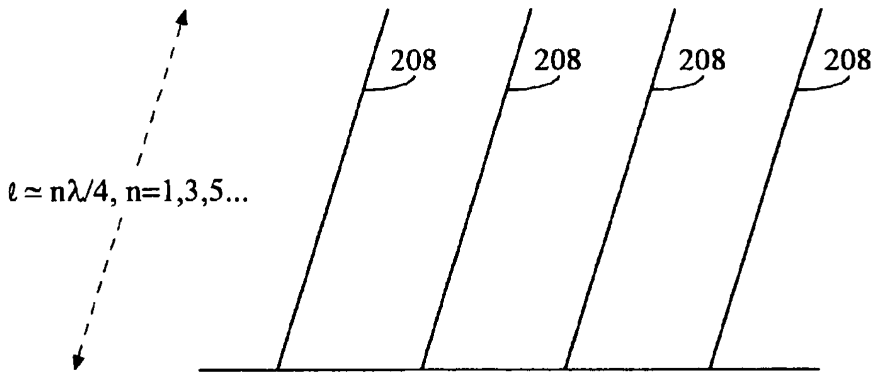


FIG. 2A

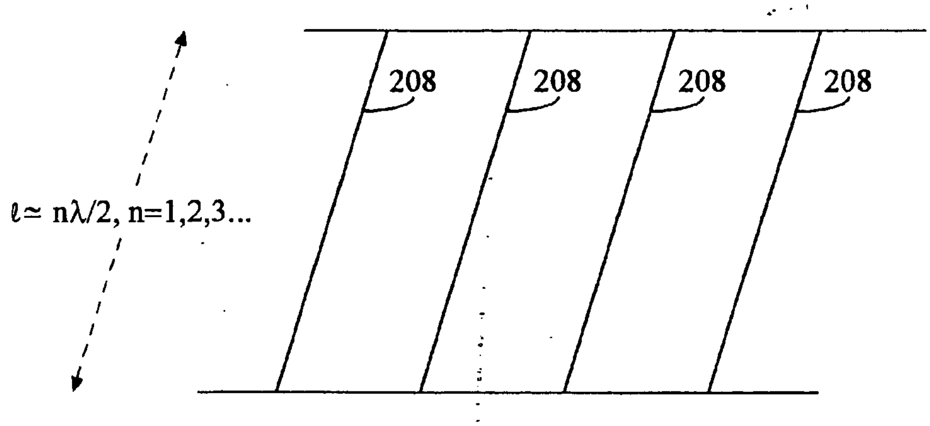


FIG. 2B

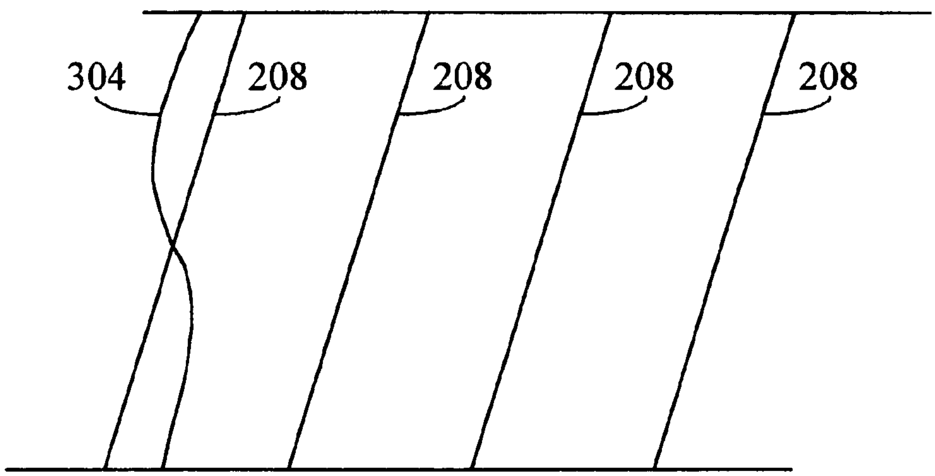


FIG. 3

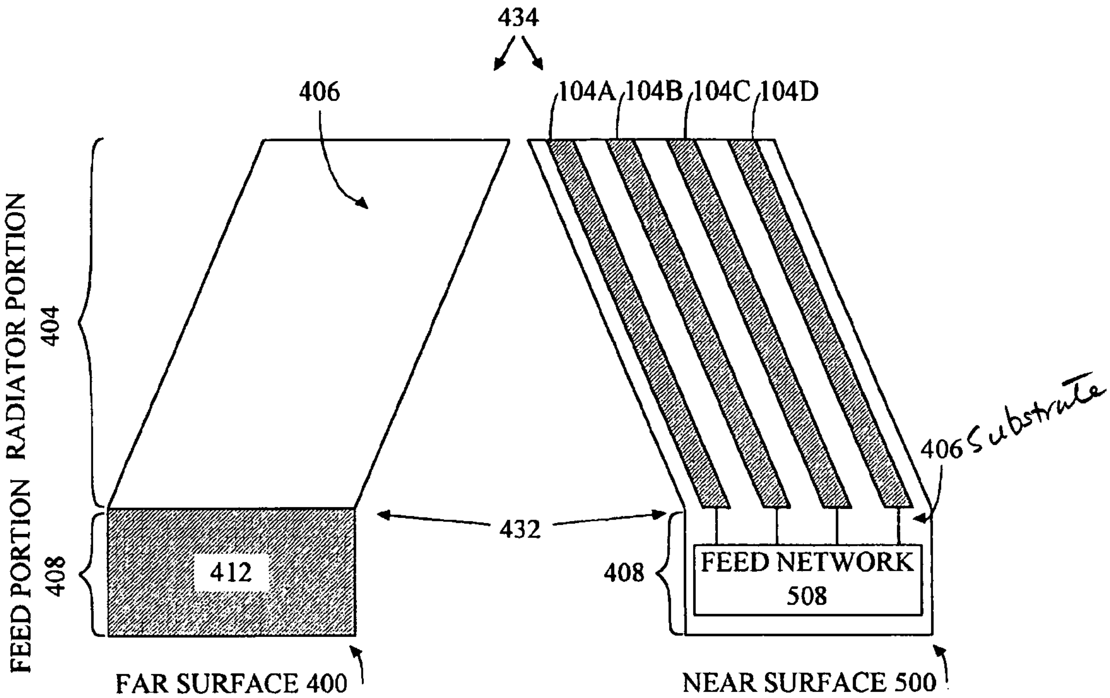


FIG. 4

FIG. 5

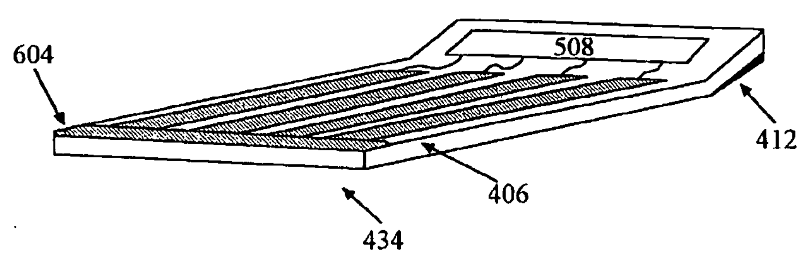


FIG. 6

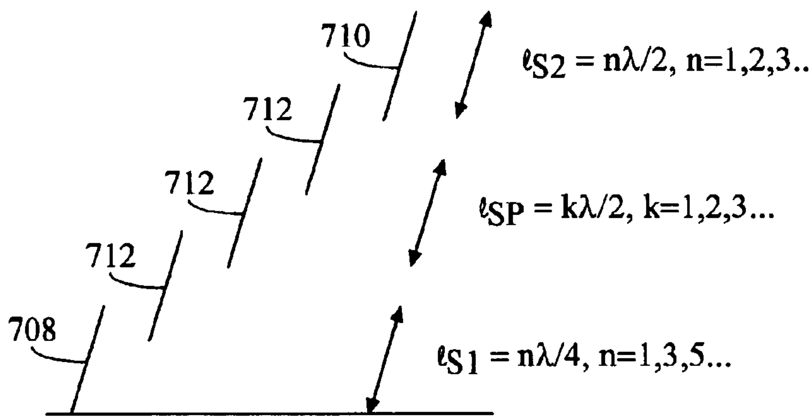
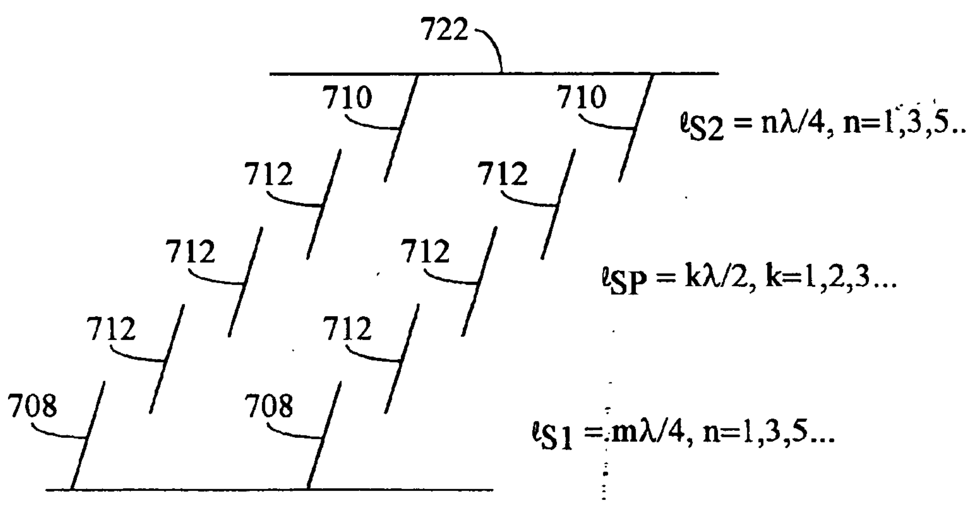

710
712
712
712
708
$\ell_{S2} = n\lambda/2$, n=1,2,3...
$\ell_{SP} = k\lambda/2$, k=1,2,3...
$\ell_{S1} = n\lambda/4$, n=1,3,5...

FIG. 7A


722
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$\ell_{S2} = n\lambda/4$, n=1,3,5...
$\ell_{SP} = k\lambda/2$, k=1,2,3...
$\ell_{S1} = m\lambda/4$, n=1,3,5...

FIG. 7B

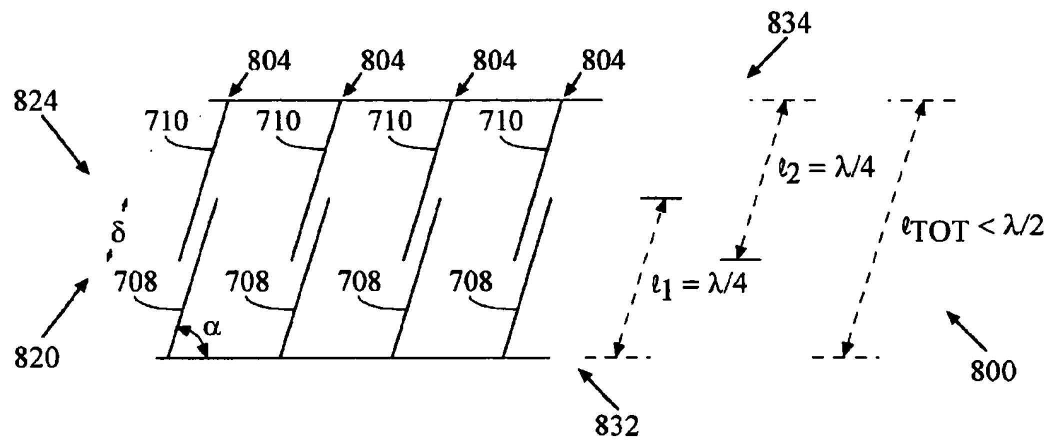
834
804
804
804
804
824
710
710
710
710
$\ell_2 = \lambda/4$
δ
$\ell_{TOT} < \lambda/2$
708
708
708
708
$\ell_1 = \lambda/4$
α
820
800
832

FIG. 8A

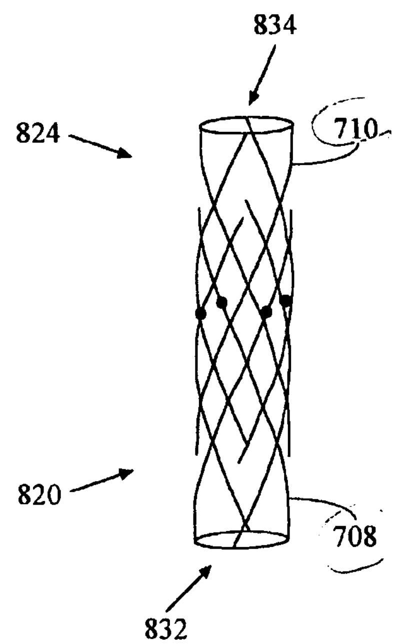
834
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FIG. 8B

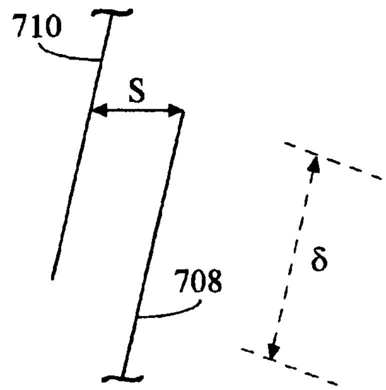


FIG. 9A

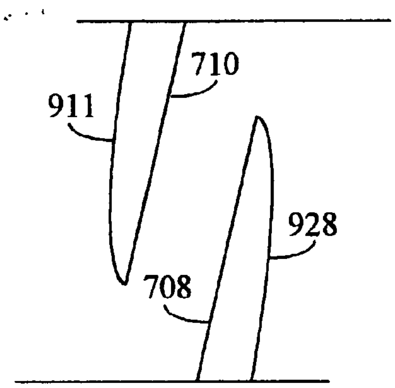


FIG. 9B

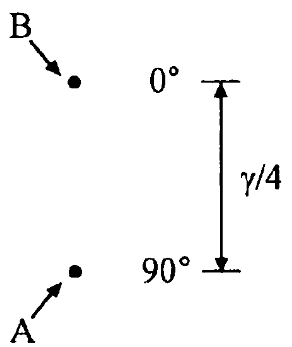


FIG. 10A

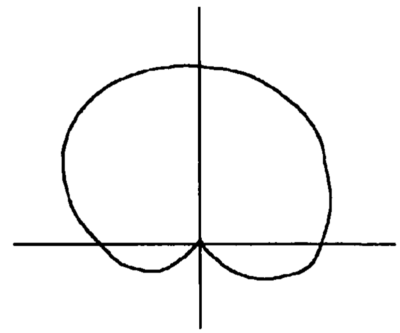


FIG. 10B

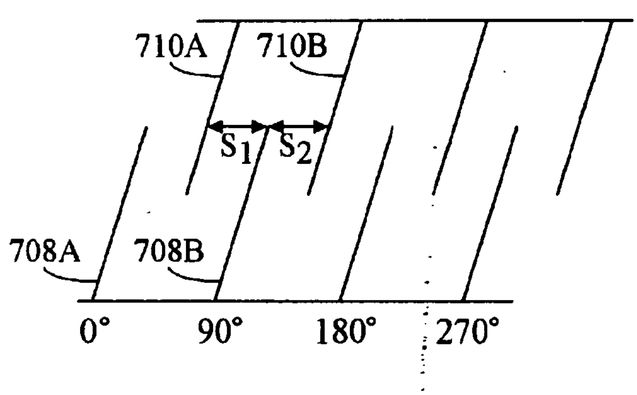
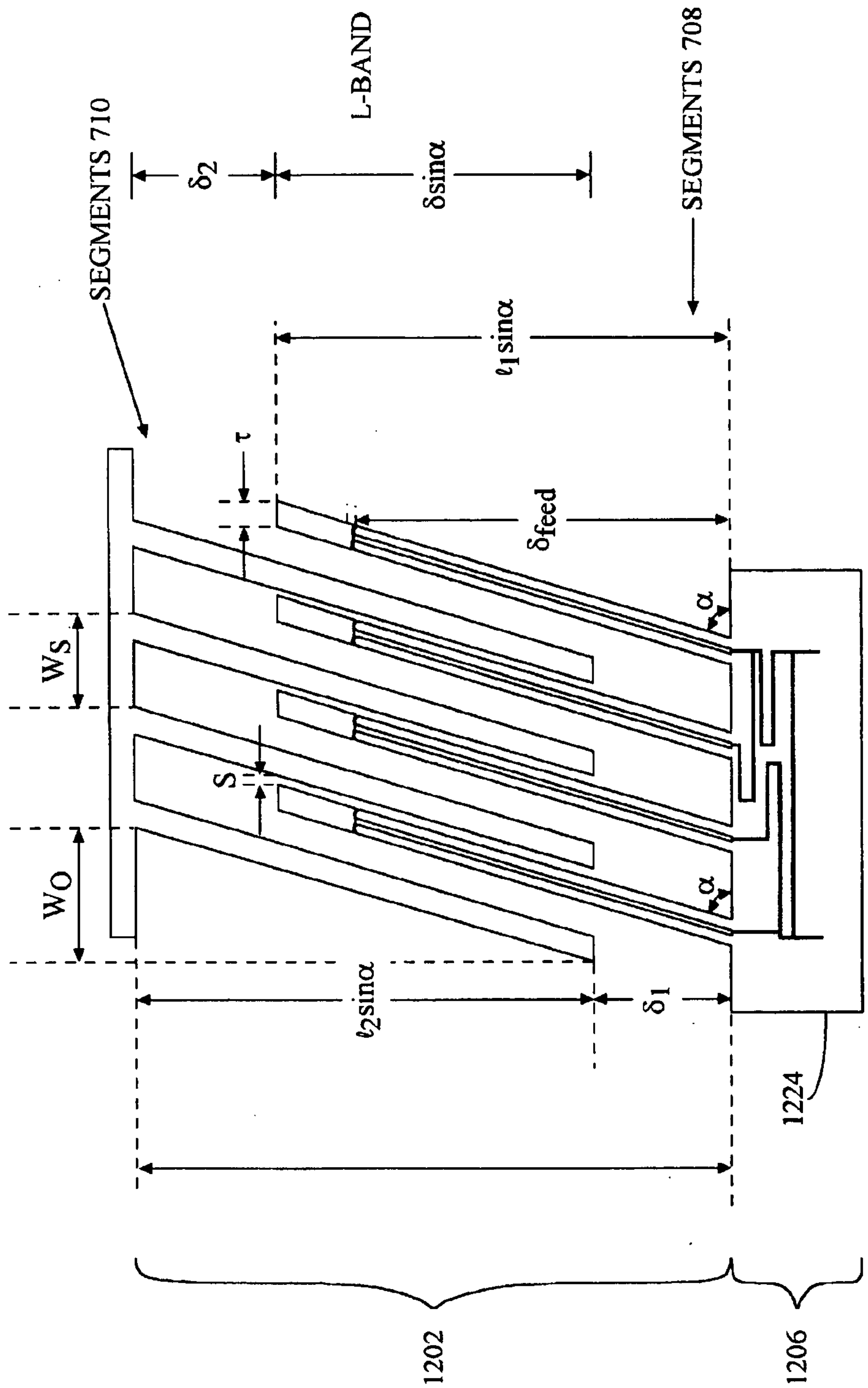


FIG. 11



SEGMENTS 710
L-BAND
SEGMENTS 708
δ_2
$\delta \sin\alpha$
$\ell_1 \sin\alpha$
τ
δ_{feed}
α
W_S
S
α
W_O
$\ell_2 \sin\alpha$
δ_1
1224
1202
1206

FIG. 12

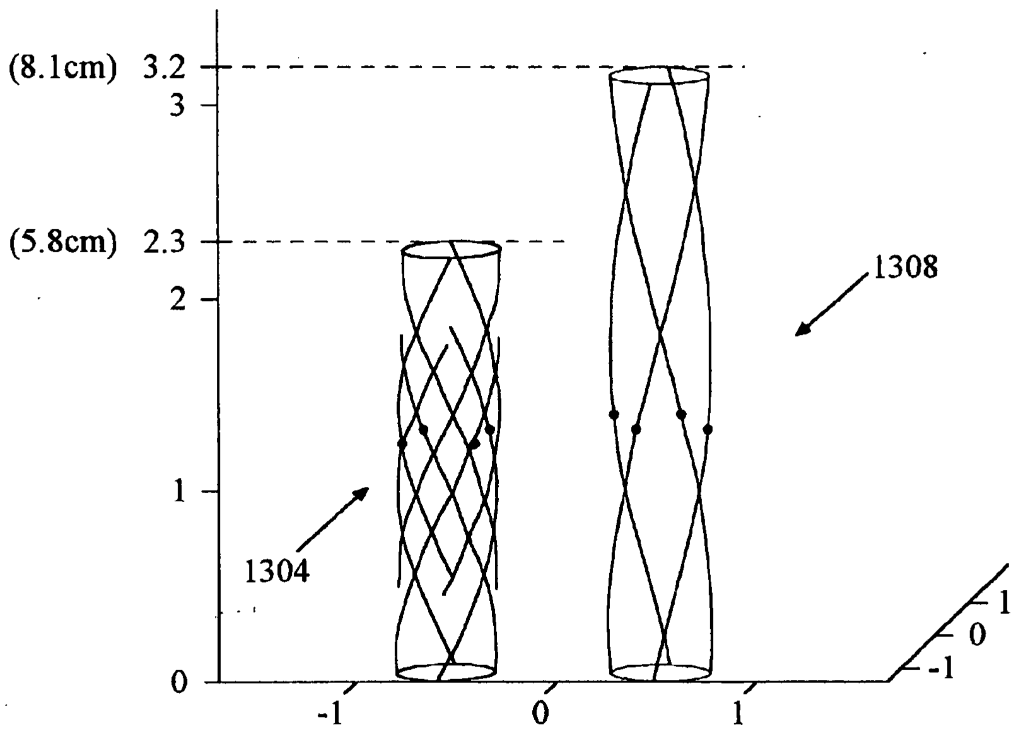


FIG. 13

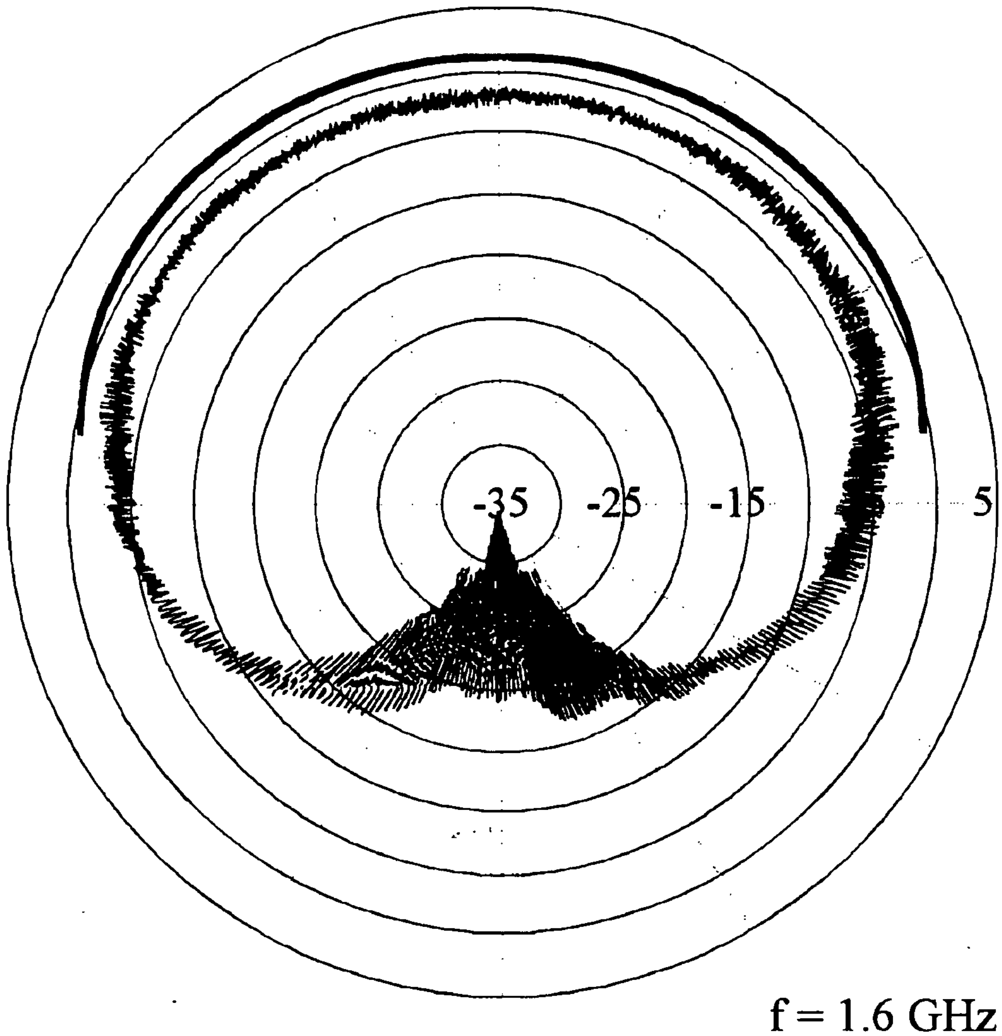


FIG. 14A

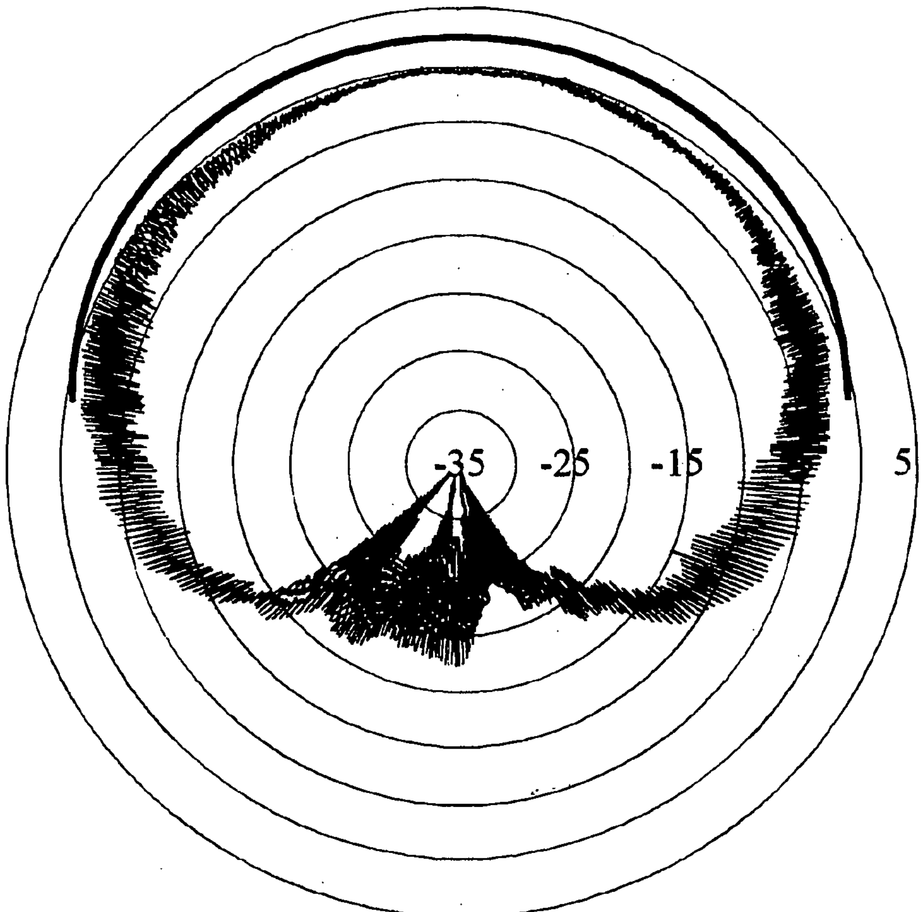


FIG. 14B

COUPLED MULTI-SEGMENT HELICAL ANTENNA

BACKGROUND OF THE INVENTION

I. Field of the Invention

This invention relates generally to helical antennas and more specifically to a helical antenna having coupled radiator segments.

II. Field of the Invention

Contemporary personal communication devices are enjoying widespread use in numerous mobile and portable applications. With traditional mobile applications, the desire to minimize the size of the communication device, such as a mobile telephone for example, led to a moderate level of downsizing. However, as the portable, hand-held applications increase in popularity, the demand for smaller and smaller devices increases dramatically. Recent developments in processor technology, battery technology and communications technology have enabled the size and weight of the portable device to be reduced drastically over the past several years.

One area in which reductions in size are desired is the devices antenna. The size and weight of the antenna play an important role in downsizing the communication device. The overall size of the antenna can impact the size of the device's body. Smaller diameter and shorter length antennas can allow smaller overall device sizes as well as smaller body sizes.

Size of the device is not the only factor that needs to be considered in designing antennas for portable applications. Another factor to be considered in designing antennas is attenuation and/or blockage effects resulting from the proximity of the user's head to the antenna during normal operations. Yet another factor is the characteristics of the communication link, such as, for example, desired radiation patterns and operating frequencies.

An antenna that finds widespread usage in satellite communication systems is the helical antenna. One reason for the helical antenna's popularity in satellite communication systems is its ability to produce and receive circularly-polarized radiation employed in such systems. Additionally, because the helical antenna is capable of producing a radiation pattern that is nearly hemispherical, the helical antenna is particularly well suited to applications in mobile satellite communication systems and in satellite navigational systems.

Conventional helical antennas are made by twisting the radiators of the antenna into a helical structure. A common helical antenna is the quadrifilar helical antenna which utilizes four radiators spaced equally around a core and excited in phase quadrature (i.e., the radiators are excited by signals that differ in phase by one-quarter of a period or 90°). The length of the radiators is typically an integer multiple of a quarter-wavelength of the operating frequency of the communication device. The radiation patterns are typically adjusted by varying the pitch of the radiator, the length of the radiator (in integer multiples of a quarter-wavelength), and the diameter of the core.

Conventional helical antennas can be made using wire or strip technology. With strip technology, the radiators of the antenna are etched or deposited onto a thin, flexible substrate. The radiators are positioned such that they are parallel to each other, but at an obtuse angle to one or more edges of the substrate. The substrate is then formed, or rolled, into a cylindrical, conical, or other appropriate shape causing the strip radiators to form a helix.

This conventional helical antenna, however, also has the characteristic that the radiator lengths are an integer multiple of one-quarter wavelength of the desired resonant frequency, resulting in an overall antenna length that is longer than desired for some portable or mobile applications.

SUMMARY OF THE INVENTION

The present invention is directed toward a helical antenna having one or more helically wound radiators. The radiators are wound such that the antenna is in a cylindrical, conical, or other appropriate shape to optimize radiation patterns. According to the invention, each radiator is comprised of a set of two or more radiator segments. Each segment in the set is physically separate from but electromagnetically coupled to the other segment(s) in the set. The length of the segments in the set is chosen such that the set (i.e., the radiator) resonates at a particular frequency. Because the segments in a set are physically separate but electromagnetically coupled to one another, the length at which the radiator resonates for a given frequency can be made shorter than that of a conventional helical antenna radiator.

Therefore, an advantage of the invention is that for a given operating frequency, the radiator portion of the coupled multi-segment helical antenna can be made to resonate at a shorter total radiator length and/or in a smaller volume than a conventional helical antenna with the same effective resonant length.

Another advantage of the coupled multi-segment helical antenna is that it can be easily tuned to a given frequency by adjusting or trimming the length of the radiator segments. Because the radiators are not a single contiguous length, but instead are made up of a set of two or more overlapping segments, the length of the segments can easily be modified after the antenna has been made to properly tune the frequency of the antenna by trimming the radiators. Additionally, the overall radiation pattern of the antenna is essentially unchanged by the tuning because the overall physical length of the radiator portion of the antenna is unchanged by the trimming.

Yet another advantage of the invention is that its directional characteristics can be adjusted to maximize signal strength in a preferred direction, such as along the axis of the antenna. Thus, for certain applications, such as satellite communications for example, the directional characteristics of the antenna can be optimized to maximize signal strength in the upward direction, away from the ground.

Further features and advantages of the present invention, as well as the structure and operation of various embodiments of the present invention, are described in detail below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout, the left-most digit(s) of a reference number identifies the drawing in which the reference number first appears, and wherein:

FIG. 1A is a diagram illustrating a conventional wire quadrifilar helical antenna;

FIG. 1B is a diagram illustrating a conventional strip quadrifilar helical antenna;

FIG. 1C is a diagram illustrating a tapered strip quadrifilar helical antenna;

FIG. 2A is a diagram illustrating a planar representation of an open termination quadrifilar helical antenna;

FIG. 2B is a diagram illustrating a planar representation of a shorted termination quadrifilar helical antenna;

FIG. 3 is a diagram illustrating current distribution on a radiator of a shorted quadrifilar helical antenna;

FIG. 4 is a diagram illustrating a far surface of an etched substrate of a strip helical antenna;

FIG. 5 is a diagram illustrating a near surface of an etched substrate of a strip helical antenna;

FIG. 6 is a diagram illustrating a perspective view of an etched substrate of a strip helical antenna;

FIG. 7A is a diagram illustrating an open coupled multi-segment radiator having five coupled segments according to one embodiment of the invention;

FIG. 7B is a diagram illustrating a pair of shorted coupled multi-segment radiators according to one embodiment of the invention.

FIG. 8A is a diagram illustrating a planar representation of a shorted coupled multi-segment quadrifilar helical antenna according to one embodiment of the invention;

FIG. 8B is a diagram illustrating a coupled multi-segment quadrifilar helical antenna formed into a cylindrical shape according to one embodiment of the invention;

FIG. 9A is a diagram illustrating overlap δ and spacing s of radiator segments according to one embodiment of the invention;

FIG. 9B is a diagram illustrating example current distributions on radiator segments of the coupled multi-segment helical antenna;

FIG. 10A is a diagram illustrating two point sources radiating signals differing in phase by 90°;

FIG. 10B is a diagram illustrating field patterns for the point sources illustrated in FIG. 10A;

FIG. 11 is a diagram illustrating an embodiment in which each segment is placed equidistant from segments on either side;

FIG. 12 is a diagram illustrating an example implementation of a coupled multi-segment antenna according to one embodiment of the invention;

FIG. 13 is a diagram illustrating a comparison between radiator portions of a conventional quadrifilar helical antenna and a coupled multi-segment quadrifilar helical antenna;

FIG. 14A is a diagram illustrating a radiation pattern of an example implementation of a coupled multi-segment quadrifilar helical antenna operating in the L-Band; and

FIG. 14B is a diagram illustrating a radiation pattern of an example implementation of a coupled multi-segment quadrifilar helical antenna operating in the S-Band.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

1. Overview and Discussion of the Invention

The present invention is directed toward a helical antenna having coupled multi-segment radiators to shorten the length of the radiators for a given resonant frequency, thereby reducing the overall length of the antenna. The manner in which this is accomplished is described in detail below according to several embodiments.

2. Example Environment

In the broadest sense, the invention can be implemented in any system for which helical antenna technology can be utilized. One example of such an environment is a communication system in which users having fixed, mobile and/or portable telephones communicate with other parties through a satellite communication link. In this example environment, the telephone is required to have an antenna tuned to the frequency of the satellite communication link.

The present invention is described in terms of this example environment. Description in these terms is provided for convenience only. It is not intended that the invention be limited to application in this example environment. In fact, after reading the following description, it will become apparent to a person skilled in the relevant art how to implement the invention in alternative environments.

3. Conventional Helical Antennas

Before describing the invention in detail, it is useful to describe the radiator portions of some conventional helical antennas. Specifically, this section of the document describes radiator portions of some conventional quadrifilar helical antennas. FIGS. 1A and 1B are diagrams illustrating a radiator portion 100 of a conventional quadrifilar helical antenna in wire form and in strip form, respectively. The radiator portion 100 illustrated in FIGS. 1A and 1B is that of a quadrifilar helical antenna, meaning it has four radiators 104 operating in phase quadrature. As illustrated in FIGS. 1A and 1B, radiators 104 are wound to provide circular polarization.

FIGS. 2A and 2B are diagrams illustrating planar representations of a radiator portion of conventional quadrifilar helical antennas. In other words, FIGS. 2A and 2B illustrate the radiators as they would appear if the antenna cylinder were "unrolled" on a flat surface. FIG. 2A is a diagram illustrating a quadrifilar helical antenna in which the radiators are open or not connected together at the far end. For such a configuration, the resonant length l of radiators 208 is an odd integer multiple of a quarter-wavelength of the desired resonant frequency.

FIG. 2B is a diagram illustrating a quadrifilar helical antenna in which the radiators are shorted, interconnected, or connected together at the far end. In this case the resonant length l of radiators 208 is an even integer multiple of a quarter-wavelength of the desired resonant frequency. Note that in both cases, the stated resonant length l is approximate, because a small adjustment is usually needed to compensate for non-ideal short and open terminations.

FIG. 3 is a diagram illustrating a planar representation of a radiator portion of a quadrifilar helical antenna 300, which includes radiators 208 having a length $l=\lambda/2$, where λ is the wavelength of the desired resonant frequency of the antenna. Curve 304 represents the relative magnitude of current for a signal on a radiator 208 that resonates at a frequency of $f=v/\lambda$, where v is the velocity of the signal in the radiator medium.

Example implementations of a quadrifilar helical antenna implemented using printed circuit board techniques (a strip antenna) are described in more detail with reference to FIGS. 4–6. The strip quadrifilar helical antenna is comprised of strip radiators 104 etched onto a dielectric substrate 406. The substrate is a thin flexible material that is rolled into a cylindrical shape such that radiators 104 are helically wound about a central axis of the cylinder.

FIGS. 4–6 illustrate the components used to fabricate a quadrifilar helical antenna 100. FIGS. 4 and 5 present a view of a far surface 400 and near surface 500 of substrate 406, respectively. The antenna 100 includes a radiator portion 404, and a feed portion 408.

In the embodiments described and illustrated herein, the antennas are described as being made by forming the substrate into a cylindrical shape with the near surface being

on the outer surface of the formed cylinder. In alternative embodiments, the substrate is formed into the cylindrical shape with the far surface being on the outer surface of the cylinder.

In one embodiment, dielectric substrate 100 is a thin, flexible layer of polytetraflouroethalene (PTFE), a PTFE/glass composite, or other dielectric material. In one embodiment, substrate 406 is on the order of 0.005 in., or 0.13 mm thick, although other thicknesses can be chosen. Signal traces and ground traces are provided using copper. In alternative embodiments, other conducting materials can be chosen in place of copper depending on cost, environmental considerations and other factors.

In the embodiment illustrated in FIG. 5, feed network 508 is etched onto feed portion 408 to provide the quadrature phase signals (i.e., the 0°, 90°, 180° and 270° signals) that are provided to radiators 104 (104A–D). Feed portion 408 of far surface 400 provides a ground plane 412 for feed circuit 508. Signal traces for feed circuit 508 are etched onto near surface 500 of feed portion 408.

For purposes of discussion, radiator portion 404 has a first end 432 adjacent to feed portion 408 and a second end 434 (on the opposite end of radiator portion 404). Depending on the antenna embodiment implemented, radiators 104 can be etched into far surface 400 of radiator portion 404. The length at which radiators 104 extend from first end 432 toward second end 434 is approximately an integer multiple of a quarter-wavelength of the desired resonant frequency.

In such an embodiment where radiators 104 are an integer multiple of $\lambda/2$ in length, radiators 104 are electrically connected to each other (i.e., shorted or short circuited) at second end 434. This connection can be made by a conductor across second end 434 which forms a ring 604 around the circumference of the antenna when the substrate is formed into a cylinder. FIG. 6 is a diagram illustrating a perspective view of an etched substrate of a strip helical antenna having a shorting ring 604 at second end 434.

One conventional quadrifilar helical antenna is described in U.S. Pat. No. 5,198,831 to Burrell, et. al. (referred to as the 831 patent), which is incorporated herein by reference. The antenna described in the 831 patent is a printed circuit-board antenna having the antenna radiators etched or otherwise deposited on a dielectric substrate. The substrate is formed into a cylinder resulting in a helical configuration of the radiators.

Another conventional quadrifilar helical antenna is disclosed in U.S. Pat. No. 5,255,005 to Terret et al (referred to as the 005 patent) which is incorporated herein by reference. The antenna described in the 005 patent is a quadrifilar helical antenna formed by two bifilar helices positioned orthogonally and excited in phase quadrature. The disclosed antenna also has a second quadrifilar helix that is coaxial and electromagnetically coupled with the first helix to improve the passband of the antenna.

Yet another conventional quadrifilar helical antenna is disclosed in U.S. Pat. No. 5,349,365, to Ow et al (referred to as the 365 patent) which is incorporated herein by reference. The antenna described in the 365 patent is a quadrifilar helical antenna designed in wireform as described above with reference to FIG. 1A.

4. Coupled Multi-Segment Helical Antenna Embodiments

Having thus briefly described various forms of a conventional helical antenna, a coupled multi-segment helical antenna according to the invention is now described in terms of several embodiments. In order to reduce the length of radiator portion 100 of the antenna, the invention utilizes coupled multi-segment radiators that allow for resonance at a given frequency at shorter lengths than would otherwise be needed for a conventional helical antenna with an equivalent resonant length.

FIGS. 7A and 7B are diagrams illustrating planar representations of example embodiments of coupled-segment helical antennas. FIG. 7A illustrates a coupled multi-segment radiator 706 terminated in an open-circuit (not shorted together) according to one single-filar embodiment. An antenna terminated in an open-circuit such as this may be used in a single-filar, bifilar, quadrifilar, or other x-filar implementation.

The embodiment illustrated in FIG. 7A is comprised of a single radiator 706. Radiator 706 is comprised of a set of radiator segments. This set is comprised of two end segments 708, 710 and p intermediate segments 712, where p=0, 1, 2, 3 . . . (the case where p=3 is illustrated). Intermediate segments are optional (i.e., p can equal zero). End segments 708, 710 are physically separate from but electromagnetically coupled to one another. Intermediate segments 712 are positioned between end segments 708, 710 and provide electromagnetic coupling between end segments 708, 710.

In the open termination embodiment, the length l_{s1} of segment 708 is an odd-integer multiple of one-quarter wavelength of the desired resonant frequency. The length l_{s2} of segment 710 is an integer multiple of one-half the wavelength of the desired resonant frequency. The length l_p of each of the p intermediate segments 712 is an integer multiple of one-half the wavelength of the desired resonant frequency. In the illustrated embodiment, there are three intermediate segments 712 (i.e., p=3).

FIG. 7B illustrates radiators 706 of the helical antenna when terminated in a short or connector 722. This shorted implementation is not suitable for a single-filar antenna, but can be used for bifilar, quadrifilar or other x-filar antennas. As with the open termination embodiment, radiators 706 are comprised of a set of radiator segments. This set is comprised of two end segments 708, 710 and p intermediate segments 712, where p=0, 1, 2, 3 . . . (the case where p=3 is illustrated). Intermediate segments are optional (i.e., p can equal zero). End segments 708, 710 are physically separate from but electromagnetically coupled to one another. Intermediate segments 712 are positioned between end segments 708, 710 and provide electromagnetic coupling between end segments 708, 710.

In the shorted embodiment, the length l_{s1} of segment 708 is an odd-integer multiple of one-quarter wavelength of the desired resonant frequency. The length l_{s2} of segment 710 is an odd-integer multiple of one-quarter wavelength of the desired resonant frequency. The length l_p of each of the p intermediate segments 712 is an integer multiple of one-half the wavelength of the desired resonant frequency. In the illustrated embodiment, there are three intermediate segments 712 (i.e., p=3).

FIGS. 8A and 8B are diagrams illustrating a coupled multi-segment quadrifilar helical antenna radiator portion 800 according to one embodiment of the invention. FIGS. 8A and 8B illustrate one example implementation of the antenna illustrated in FIG. 7B, where p=zero (i.e., there are no intermediate segments 712) and the lengths of segments 708, 710 are one-quarter wavelength.

The radiator portion 800 illustrated in FIG. 8A is a planar representation of a quadrifilar helical antenna, having four coupled radiators 804. Each coupled radiator 804 in the coupled antenna is actually comprised of two radiator segments 708, 710 positioned in close proximity with one another such that the energy in radiator segment 708 is coupled to the other radiator segment 710.

More specifically, according to one embodiment, radiator portion **800** can be described in terms of having two sections **820, 824**. Section **820** is comprised of a plurality of radiator segments **708** extending from a first end **832** of the radiator portion **800** toward the second end **834** of radiator portion **800**. Section **824** is comprised of a second plurality of radiator segments **710** extending from second end **834** of the radiator portion **800** toward first end **832**. Toward the center area of radiator portion **800**, a part of each segment **708** is in close proximity to an adjacent segment **710** such that energy from one segment is coupled into the adjacent segment in the area of proximity. This relative proximity is referred to in this document as overlap.

In a preferred embodiment, each segment **708, 710** is of a length of approximately $l_1=l_2=\lambda/4$. The overall length of a single radiator comprising two segments **708, 710** is defined as l_{tot}. The amount one segment **708** overlaps another segment **710** is defined as $\delta=l_1+l_2-l_{tot}$.

For a resonant frequency $f=v/\lambda$ the overall length of a radiator l_{tot} is less than the half-wavelength length of $\lambda/2$. In other words, as a result of coupling, a radiator, comprising a pair of coupled segments **708, 710**, resonates at frequency $f=v/\lambda$ even though the overall length of that radiator is less than a length of $\lambda/2$. Therefore, radiator portion **800** of a half-wavelength coupled multi-segment quadrifilar helical antenna is shorter than the radiator portion of conventional half-wavelength quadrifilar helical antenna **800** for a given frequency f.

For a clearer illustration of the reduction in size gained by using the coupled configuration, compare the radiator portions **800** illustrated in FIG. **8** with those illustrated in FIG. **3**. For a given frequency $f=v/\lambda$, the length l of radiator portion **300** of the conventional antenna is $\lambda/2$, while the length l_{tot} of radiator portion **800** of the coupled radiator segment antenna is $<\lambda/2$.

As stated above, in one embodiment, segments **708, 710** are of a length $l_1=l_2=\lambda/4$. The length of each segment can be varied such that l_1 is not necessarily equal to l_2, and such that they are not equal to $\lambda/4$. The actual resonant frequency of each radiator is a function of the length of radiator segments **708, 710** the separation distance s between radiator segments **708, 710** and the amount which segments **708, 710** overlap each other.

Note that changing the length of one segment **708** with respect to the other segment **710** can be used to adjust the bandwidth of the antenna. For example, lengthening l_1 such that it is slightly greater than $\lambda/4$ and shortening l_2 such that it is slightly shorter than $\lambda/4$, can increase the bandwidth of the antenna.

FIG. **8B** illustrates the actual helical configuration of a coupled multi-segment quadrifilar helical antenna according to one embodiment of the invention. This illustrates how each radiator is comprised of two segments **708, 710** in one embodiment. Segment **708** extends in a helical fashion from first end **832** of the radiator portion toward second end **834** of the radiator portion. Segment **710** extends in a helical fashion from second end **834** of the radiator portion toward first end **832** of the radiator portion. FIG. **8B** further illustrates that a portion of segments **708, 710** overlap such that they are electromagnetically coupled to one another.

FIG. **9A** is a diagram illustrating the separation s and overlap δ between radiator segments **708, 710**. Separation s is chosen such that a sufficient amount of energy is coupled between the radiator segments **708, 710** to allow them to function as a single radiator of an effective electrical length of approximately $\lambda/2$ and integer multiples thereof.

Spacing of radiator segments **708, 710** closer than this optimum spacing results in greater coupling between segments **708, 710**. As a result, for a given frequency f the length of segments **708, 710** must increase to enable resonance at the same frequency f. This can be illustrated by the extreme case of segments **708, 710** being physically connected (i.e., s=0). In this extreme case, the total length of segments **708, 710** must equal $\lambda/2$ for the antenna to resonate. Note that in this extreme case, the antenna is no longer really coupled according to the usage of the term in this specification, and the resulting configuration is actually that of a conventional helical antenna such as that illustrated in FIG. 3.

Similarly, increasing the amount of overlap δ of segments **708, 710** increases the coupling. Thus as overlap δ increases, the length of segments **708, 710** increases as well.

To qualitatively understand the optimum overlap and spacing for segments **708, 710**, refer to FIG. 9B. FIG. **9B** represents a magnitude of the current on each segment **708, 710**. Current strength indicators **911, 928** illustrate that each segment ideally resonates at $\lambda/4$, with the maximum signal strength at the outer ends and the minimum at the inner ends.

To optimize antenna configurations for the coupled radiator segment antenna, the inventors utilized modeling software to determine correct segment lengths l_1, l_2, overlap δ, and spacing s, among other parameters. One such software package is the Antenna Optimizer (AO) software package. AO is based on a method of moments electromagnetic modeling algorithm. AO Antenna Optimizer version 6.35, copyright 1994, was written by and is available from Brian Beezley, of San Diego, Calif.

Note that there are certain advantages obtained by using a coupled configuration as described above with reference to FIGS. **8A** and **8B**. With both the conventional antenna and the coupled radiator segment antenna, current is concentrated at the ends of the radiators. Pursuant to array factor theory, this can be used to an advantage with the coupled radiator segment antenna in certain applications.

To explain, FIG. **10A** is a diagram illustrating two point sources, A, B, where source A is radiating a signal having a magnitude equal to that of the signal of source B but lagging in phase by 90° (the $e^{j\omega t}$ convention is assumed). Where sources A and B are separated by a distance of $\lambda/4$, the signals add in phase in the direction traveling from A to B and add out of phase in the direction from B to A. As a result, very little radiation is emitted in the direction from B to A. A typical representative field pattern shown in FIG. **10B** illustrates this point.

Thus, when the sources A and B are oriented such that the direction from A to B points upward, away from the ground, and the direction from B to A points toward the ground, the antenna is optimized for most applications. This is because it is rare that a user desires an antenna that directs signal strength toward the ground. This configuration is especially useful for satellite communications where it is desired that the majority of the signal strength be directed upward, away from the ground.

The point source antenna modeled in FIG. **10A** is not readily achievable using conventional half wavelength helical antennas. Consider the antenna radiator portion illustrated in FIG. **3**. The concentration of current strength at the ends of radiators **208** roughly approximates a point source. When radiators are twisted into a helical configuration, one end of the 90° radiator is positioned in line with the other end of the 0° radiator. Thus, this approximates two point sources in a line. However, these approximate point sources are separated by approximately $\lambda/2$ as opposed to the desired $\lambda/4$ configuration illustrated in FIG. 10A.

Note, however that the coupled radiator segment antenna according to the invention provides an implementation

where the approximated point sources are spaced at a distance closer to $\lambda/4$. Therefore, the coupled radiator segment antenna allows users to capitalize on the directional characteristics of the antenna illustrated in FIG. **10A**.

The radiator segments **708**, **710** illustrated in FIG. **8** show that segment **708** is very near its associated segment **710**, yet each pair of segments **708**, **710** are relatively far from the adjacent pair of segments. In one alternative embodiment, each segment **710** is placed equidistant from the segments **708** on either side. This embodiment is illustrated in FIG. **11**.

Referring now to FIG. **11**, each segment is substantially equidistant from each pair of adjacent segments. For example, segment **708B** is equidistant from segments **710A**, **710B**. That is, $s_1=s_2$. Similarly, segment **710A** is equidistant from segments **708A**, **708B**.

This embodiment is counterintuitive in that it appears as if unwanted coupling would exist. In other words, a segment corresponding to one phase would couple not only to the appropriate segment of the same phase, but also to the adjacent segment of the shifted phase. For example, segment **708B**, the 90° segment would couple to segment **710A** (the 0° segment) and to segment **710B** (the 90° segment). Such coupling is not a problem because the radiation from the top segments **710** can be thought of as two separate modes. One mode resulting from coupling to adjacent segments to the left and the other mode from coupling to adjacent segments to the right. However, both of these modes are phased to provide radiation in the same direction. Therefore, this double-coupling is not detrimental to the operation of the coupled multi-segment antenna.

5. Example Implementations

FIG. **12** is a diagram illustrating an example implementation of a coupled radiator segment antenna according to one embodiment of the invention. Referring now to FIG. **12**, the antenna comprises a radiator portion **1202** and a feed portion **1206**. Radiator portion includes segments **708**, **710**. Dimensions provided in FIG. **12** illustrate the contribution of segments **708**, **710** and the amount of overlap δ to the overall length of radiator portion **1202**.

The length of segments in a direction parallel to the axis of the cylinder is illustrated as $l_1\sin\alpha$ for segments **708** and $l_2\sin\alpha$ for segments **710**, where α is the inside angle of segments **708**, **710**.

Segment overlap as illustrated above in FIGS. **8A** and **9A**, is illustrated by the reference character δ. The amount of overlap in a direction parallel to the axis of the antenna is given by $\delta\sin\alpha$, as illustrated in FIG. **12**.

Segments **708**, **710** are separated by a spacing s, which can vary as described above. The distance between the end of a segment **708**, **710** and the end of radiator portion **1202** is defined as the gap and illustrated by the reference characters γ_1, γ_2, respectively. The gaps γ_1, γ_2 can, but do not have to be equal to each other. Again, as described above, the length of segments **708** can be varied with respect to that of segments **710**.

The amount of offset of a segment **710** from one end to the next is illustrated by the reference character ω_0. The separation between adjacent segments **710** is illustrated by the reference character ω_o, and is determined by the helix diameter.

Feed portion **1206** includes an appropriate feed network to provide the quadrature phase signals to the radiator segments **708**. Feed networks are well known to those of ordinary skill in the art and are, thus, not described in detail herein.

In the embodiment illustrated in FIG. **12**, segments **708** are fed at a feed point that is positioned along segment **708** a distance from the feed network that is chosen to optimize impedance matching. In the embodiment illustrated in FIG. **12**, this distance is illustrated by the reference characters δ_{feed}.

Note that continuous line **1224** illustrates the border for a ground portion on the far surface of the substrate. The ground portion opposite segments **708** on the far surface extends to the feed point. The thin portion of segments **708** is on the near surface. At the feed point, the thickness of segments **708** on the near surface increases.

Dimensions are now provided for an example coupled radiator segment quadrifilar helical antenna suitable for operation in the L-Band at approximately 1.6 GHz. Note that this is an example only and other dimensions are possible for operation in the L-Band. Additionally, other dimensions are possible for operation in other frequency bands as well.

The overall length of radiator portion **1202** in the example L-Band embodiment is 2.30 inches (58.4 mm). In this embodiment, the pitch angle α is 73 degrees. With this angle α, the length $l_1\sin\alpha$ of segments **708** for this embodiment is 1.73 inches (43.9 mm). In the illustrated embodiment, the length of segments **710** is equal to the length of segments **708**.

In one example embodiment, segment **710** is positioned substantially equidistant from its adjacent pair of segments **708**. In one implementation of the embodiment where segments **710** are equidistant from adjacent segments **708**, the spacing $s_1=s_2=0.086$ inches. Other spacings are possible including, for example, the spacing s of segments **710** at 0.070 inches (1.8 mm) from an adjacent segment **708**.

The width τ of radiator segments **708**, **710** is 0.11 inches (2.8 mm) in this embodiment. Other widths are possible.

The example L-Band embodiment features a symmetric gap $\gamma_1=\gamma_2=0.57$ inches (14.5 mm). Where the gap γ is symmetric for both ends of the radiator portion **1202** (i.e., where $\gamma_1=\gamma_2$), radiators **708**, **710** have an overlap $\delta\sin\alpha$ of 1.16 inches(29.5 mm) (1.73 inches-0.57 inches).

The segment offset ω_0 is 0.53 inches and the segment separation ω_s is 0.393 inches (10.0 mm). The diameter of the antenna is $4\omega_s/\pi$.

In one embodiment, this is chosen such that the distance δ_{feed} from the feed point to the feed network is $\delta_{feed}=1.57$ inches (39.9 mm). Other feed points can be chosen to optimize impedance matching.

Note that the example embodiment described above is designed for use in conjunction with a 0.032 inch thick polycarbonate radome enclosing the helical antenna and contacting the radiator portion. It will become apparent to a person skilled in the art how a radome or other structure affects the wavelength of a desired frequency.

Note that in the example embodiments just described, the overall length of the L-Band antenna radiator portion is reduced from that of a conventional half-wavelength L-Band antenna. For a conventional half wavelength L-Band antenna, the length of the radiator portion is approximately 3.2 inches (i.e., $\lambda/2(\sin\alpha)$), where α is the inside angle of segments **708**, **710** with respect to the horizontal), or (81.3 mm). For the example embodiments described above, the overall length of the radiator portion **1202** is 2.3 inches (58.42 mm). This represents a substantial savings in size over the conventional antenna.

FIG. **13** is a diagram illustrating a side-by-side comparison of a half-wavelength L-Band coupled multi-segment antenna radiator portion **1304** and a conventional L-Band quadrifilar helical antenna **1308**. As is illustrated by FIG. **13**, the coupled radiator segment antenna radiator portion **1304** is significantly shorter than conventional quadrifilar helical antenna **1308**.

An example embodiment for S-Band at approximately 2.49 GHz is now described. The overall length of radiator portion **1202** in the example S-Band embodiment is 1.50 inches (38.1 mm). The pitch angle, α, in this embodiment, is 65 degrees. The length $l_1 \sin\alpha$ of segments **708** for this embodiment is 0.95 inches (24.1 mm). The length of segments **710** is equal to the lengths of segments **708**. The preferred embodiment is a spacing that positions segments **710** equidistant from this adjacent pair of segments **708** ($s_1=s_2=0.086$ inches). The width τ of radiator segments **708**, **710** is 0.11 inches (2.8 mm). The feed point δ_{feed} for 50 Ω impedance-matching is 0.60 inches.

The example S-Band embodiment features a symmetric gap (i.e., $\gamma_1=\gamma_2=0.55$ inches) for both ends of the radiator portion **1202**, the radiators **708**, **710** have an overlap $\delta\sin\alpha$ of 0.40 inches (10.2 mm) (0.95 inches–0.55 inches).

The segment offset ω_0 is 0.44 inches (11.2 mm) and the segment separation ω_s is 0.393 inches (10.0 mm). The diameter of the antenna is $4\omega_s/\pi$.

Note that the example embodiment just described is designed with a 0.032 inch thick polycarbonate radome enclosing the helical antenna (and contacting the radiator portion).

In these embodiments, the overall length of the S-Band antenna is reduced from that of a conventional half-wavelength S-Band antenna. For a conventional half wavelength S-Band antenna, the length of the radiator portion is approximately 2.0 inches ($\lambda/2(\sin\alpha)$), where α is the inside angle of segments with respect to the horizontal), or (50.8 mm). In the embodiment just described, the overall length of radiator portion **1202** is 1.5 inches.

FIG. **14A** is a diagram illustrating a radiation pattern of an example implementation of a coupled multi-segment quadrifilar helical antenna operating in the L-Band. FIG. **14B** is a diagram illustrating a radiation pattern of an example implementation of a coupled multi-segment quadrifilar helical antenna operating at S-Band. As these patterns illustrate, the antennas provide good omni-directional characteristics in the upper half-plane and exhibit good circular polarization.

In the strip embodiments discussed above, the radiator segments **708**, **710**, **712** are described as all being provided on the same surface of the substrate. In alternative embodiments, the segments need not all be positioned on the same surface of the substrate. For example, in one embodiment, segments at the first end (i.e., segments **708**) are positioned on one surface of the substrate and segments at the second end (i.e., segments **710**) are positioned on the opposite surface. This and other embodiments not requiring all of segments **708**, **710**, **712** to be on the same surface are possible because the segments do not need to be strictly edge-wise aligned for the electromagnetic energy to couple. Small offsets on the order of the thickness of the substrate do not adversely affect coupling. These embodiments allowing selective placement of segments **708**, **710**, **712** can be used to provide certain components or segments on the outside of the antenna to allow access to those components for such purposes as tuning, or making connections to the components while providing other components inside the antenna.

In some applications, it is desirable to have an antenna that operates at two frequencies. One example of such an application is a communication system operating at one frequency for transmit and a second frequency for receive. One conventional technique for achieving dual-band performance is to stack two single-band quadrifilar helical antennas end-to-end to form a single long cylinder. For example, a system designer may stack an L-Band and an S-Band antenna to achieve operational characteristics at both L and S bands. Such stacking, however, increases the overall length of the antenna. Reductions in size obtained by using coupled radiator segment antennas can provide dramatic reductions in the overall length of a stacked dual-band antenna.

One additional advantage of the segmented radiator helical antenna is that it is very easy to tune the antenna after it has already been manufactured. The antenna can be simply tuned by trimming segments **708**, **710**. Note that, if desired, this can be done without changing the overall length of the antenna.

Note that the embodiments of the coupled radiator segment antenna described above are presented in terms of a half-wavelength antenna resonating at a wavelength equal to an integer multiple of $\lambda/2$. After reading this document, it will become apparent to a person of ordinary skill in the art how to implement the invention using an antenna resonating at a wavelength equal to an odd integer multiple of $\lambda/4$ by omitting the shorting ring at the far end of the radiators.

3. Conclusion

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What we claim is:

1. A helical antenna comprising a radiator portion having a helically wound radiator extending from a first end of the radiator portion to a second end of the radiator portion, said radiator comprising:

a first radiator segment of a length substantially equal to an odd multiple of a quarter wavelength extending in a helical fashion from the first end of the radiator portion toward the second end of the radiator portion, wherein said first radiator segment is a driven radiator segment, configured for connection to a feed; and

a second radiator segment of a length substantially equal to an odd multiple of a quarter wavelength extending in a helical fashion from the second end of the radiator portion toward the first end of the radiator portion and partially overlapping said first radiator segment, wherein said second radiator segment is a parasitic radiator;

wherein said first radiator segment is in proximity with said second radiator segment in the area of overlap such that said first and second radiator segments are electromagnetically coupled to one another such that said first and second radiator segments resonate at the same selected frequency.

2. The helical antenna of claim **1**, wherein said first and second radiator segments are comprised of strip segments deposited on a dielectric substrate, wherein said dielectric substrate is shaped such that the radiator segments are wrapped in a helical fashion.

3. The helical antenna of claim **2**, wherein said dielectric substrate is formed into a cylindrical shape or a conical shape.

4. The helical antenna of claim **1**, wherein said first and second radiator segments are wire segments.

5. The helical antenna of claim **1**, wherein said first radiator segment is equal in length to said second radiator segment.

6. The helical antenna of claim 1, wherein each of said first and second radiator segments is $\lambda/4$ in length, where λ is the wavelength of a resonant frequency of the antenna.

7. The helical antenna of claim 1 comprising four radiators and further comprising a feed network for providing a quadrature phase signal to said four radiators.

8. The helical antenna of claim 1, further comprising a feed point for said first radiator segment that is spaced along said first radiator segment from said first end a distance that substantially matches the impedance of the radiator segments to a feed network.

9. The helical antenna of claim 1 further comprising one or more intermediate radiator segments positioned between said first and second radiator segments.

10. The helical antenna of claim 1, wherein a portion of said first radiator segment is in close proximity with a portion of said second radiator segment.

11. The helical antenna of claim 1, wherein said first radiator segment is connected to a feed network at said first end and said second radiator segment has an open termination at said second end.

12. The helical antenna of claim 1, wherein said second segment axially extends beyond said first segment.

13. The helical antenna of claim 1, wherein said partial overlap is defined by $\delta=l_1+l_2-l_{tot}$, where l_1 and l_2 are the lengths of said first and second radiator segments, respectively, and l_{tot} is the overall length of the radiator portion.

14. A helical antenna comprising a radiator portion having a plurality of helically wound multi-segment radiators extending from a first end of the radiator portion to a second end of the radiator portion, said multi-segment radiators each comprising at least first and second substantially parallel and overlapping segments, each of said segments being of a length substantially equal to an odd multiple of a quarter wavelength, wherein said first segment is physically separate from but electromagnetically coupled to said second segment, and wherein said first and second segments resonate at the same selected frequency.

15. The helical antenna of claim 14, wherein said first and second segments comprise strip segments deposited on a dielectric substrate.

16. The helical antenna of claim 14, wherein said first segment is equal in length to said second segment.

17. The helical antenna of claim 14, wherein said first and second radiator segments comprise wire segments.

18. The helical antenna of claim 14, wherein the effective combined length of said first and second segments is approximately an integer multiple of $\lambda/2$, where λ is the wavelength of a resonant frequency of the antenna.

19. The helical antenna of claim 14, comprising four radiators and further comprising a feed network for providing a quadrature phase signal to said four radiators.

20. The helical antenna of claim 14, further comprising a feed point for each said radiator, wherein said feed point is positioned at a distance from said first end along said first segment, wherein said distance is chosen to match the impedance of the radiators to a feed network.

21. The helical antenna of claim 14, wherein a portion of said first segment is in close proximity with a portion of said second segment.

22. The helical antenna of claim 14, wherein said radiator portion is a first radiator portion, and further comprising a second radiator portion having a plurality of helically wound segmented radiators extending from a first end of said second radiator portion to a second end of said second radiator portion, said segmented radiators each comprising first and second segments, wherein said first segment is physically separate from but electromagnetically coupled to said second segment.

23. The helical antenna of claim 22, wherein said first radiator portion is stacked coaxially with said second radiator portion.

24. The helical antenna of claim 14, wherein said radiators are helically wound into a cylindrical or conical shape.

25. A helical antenna comprising a radiator portion having a plurality of helically wound multi-segment radiators extending from a first end of the radiator portion to a second end of the radiator portion, said multi-segment radiators each comprising an elongated driven segment extending from said first end and a plurality of elongated parasitic segments, wherein each segment of said parasitic segments is substantially parallel to and overlaps an adjacent segment and said plurality of parasitic segments axially extend substantially parallel to and beyond said driven segment, wherein each of said driven segment and a last parasitic segment extending from said second end is of a length substantially equal to an odd multiple of a quarter wavelength and each of said parasitic segments intermediate said driven and last parasitic segments is of a length substantially equal to an integer multiple of a half wavelength, and wherein said driven and parasitic segments resonate at the same selected frequency.

26. A helical antenna comprising a radiator portion having a plurality of helically wound multi-segment radiators extending from a first end of the radiator portion to a second end of the radiator portion, said multi-segment radiators each comprising at least first and second segments, wherein each of said first and second segments has a length substantially equal to an odd multiple of a quarter wavelength and said first segment is physically separate from but electromagnetically coupled to said second segment, wherein said radiators further comprise one or more intermediate radiator segments positioned between said first and second segments, and wherein each of said first, second, and intermediate radiator segments resonate at the same selected frequency.

27. The helical antenna of claim 26, wherein said second radiator segments have an open termination at said second end.

28. The helical antenna of claim 26, further comprising means for shorting said plurality of second radiator segments at said second end.

29. A helical antenna comprising a radiator portion having a helically wound radiator extending from a first end of the radiator portion to a second end of the radiator portion said radiator comprising:

- a plurality of first radiator segments of a length substantially equal to an odd multiple of a quarter wavelength extending in a helical fashion from the first end of the radiator portion toward the second end of the radiator portion, wherein said first radiator segments are driven radiator segments, configured for connection to a feed;
- a plurality of second radiator segments of a length substantially equal to an odd multiple of a quarter wavelength extending in a helical fashion from the second end of the radiator portion toward the first end of the radiator portion and partially overlapping said first radiator segments, wherein said second radiator segments are parasitic radiators; and
- means for shorting said plurality of second radiator segments;
- wherein said first radiator segments are in proximity with said second radiator segments in the area of overlap such that said first and second radiator segments are electromagnetically coupled to one another such that said first and second radiator segments resonate at the same selected frequency.

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US006072441A

United States Patent [19]

Tanabe

[11] **Patent Number:** **6,072,441**

[45] **Date of Patent:** **Jun. 6, 2000**

[54] **METHOD OF PRODUCING A HELICAL ANTENNA AND THE HELICAL ANTENNA APPARATUS**

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[73] Assignee: **NEC Corporation**, Tokyo, Japan

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[51] **Int. Cl.**[7] **H01Q 1/36**

[52] **U.S. Cl.** .... **343/895**; 343/853; 343/700 MS

[58] **Field of Search** .... 343/895, 702, 343/846, 829, 725, 853, 700 MS; H01Q 1/36

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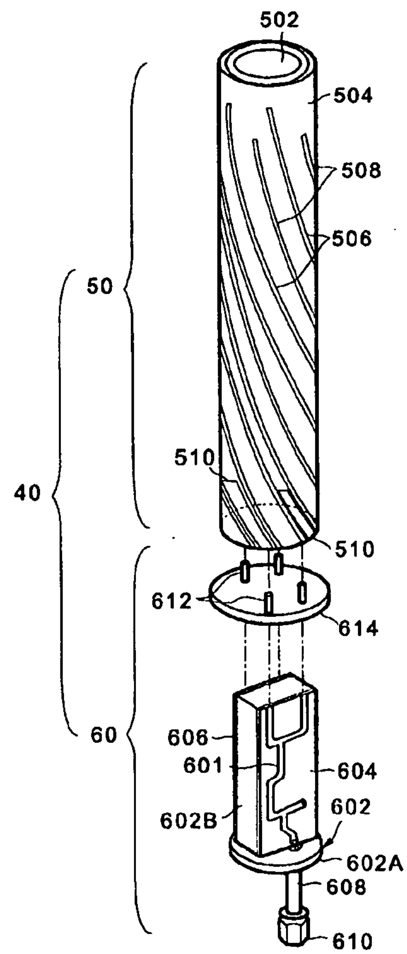
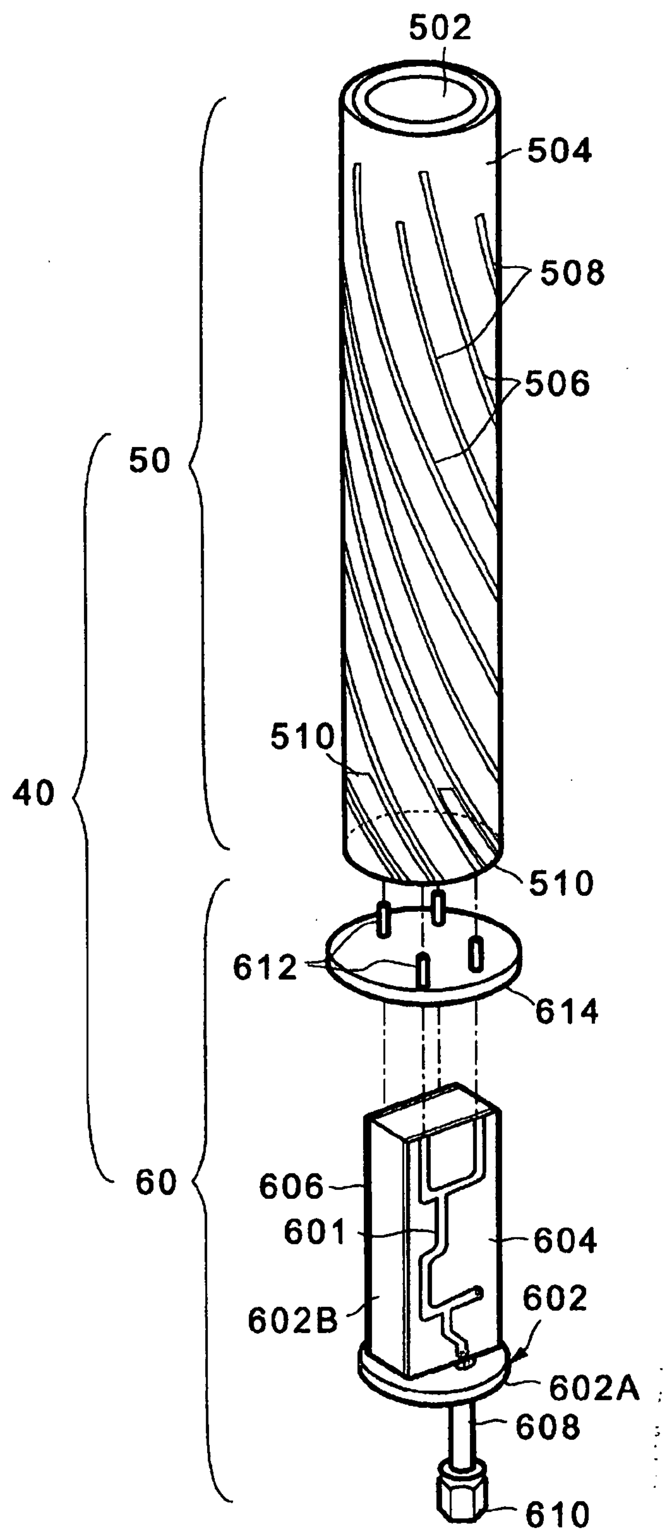
[57] **ABSTRACT**

A helical antenna capable of covering a plurality of frequency bands and using a common feeder system for antenna elements adjusted to the respective frequency bands. First and second antenna elements having lengths corresponding to wavelengths of the frequency bands to be used are arranged helically at a specified pitch angle and spaced apart in the circumferential direction of a cylindrical body on the surface of a dielectric sheet wound around the outer circumferential surface of the cylindrical body. Coupling lines to be electromagnetically coupled to one-side ends of the antenna elements being adjacent to one another are formed on the surface of the dielectric sheet. A signal is fed from a common feeder circuit through the coupling lines to the respective antenna elements.

32 Claims, 14 Drawing Sheets

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608
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Fig. 1

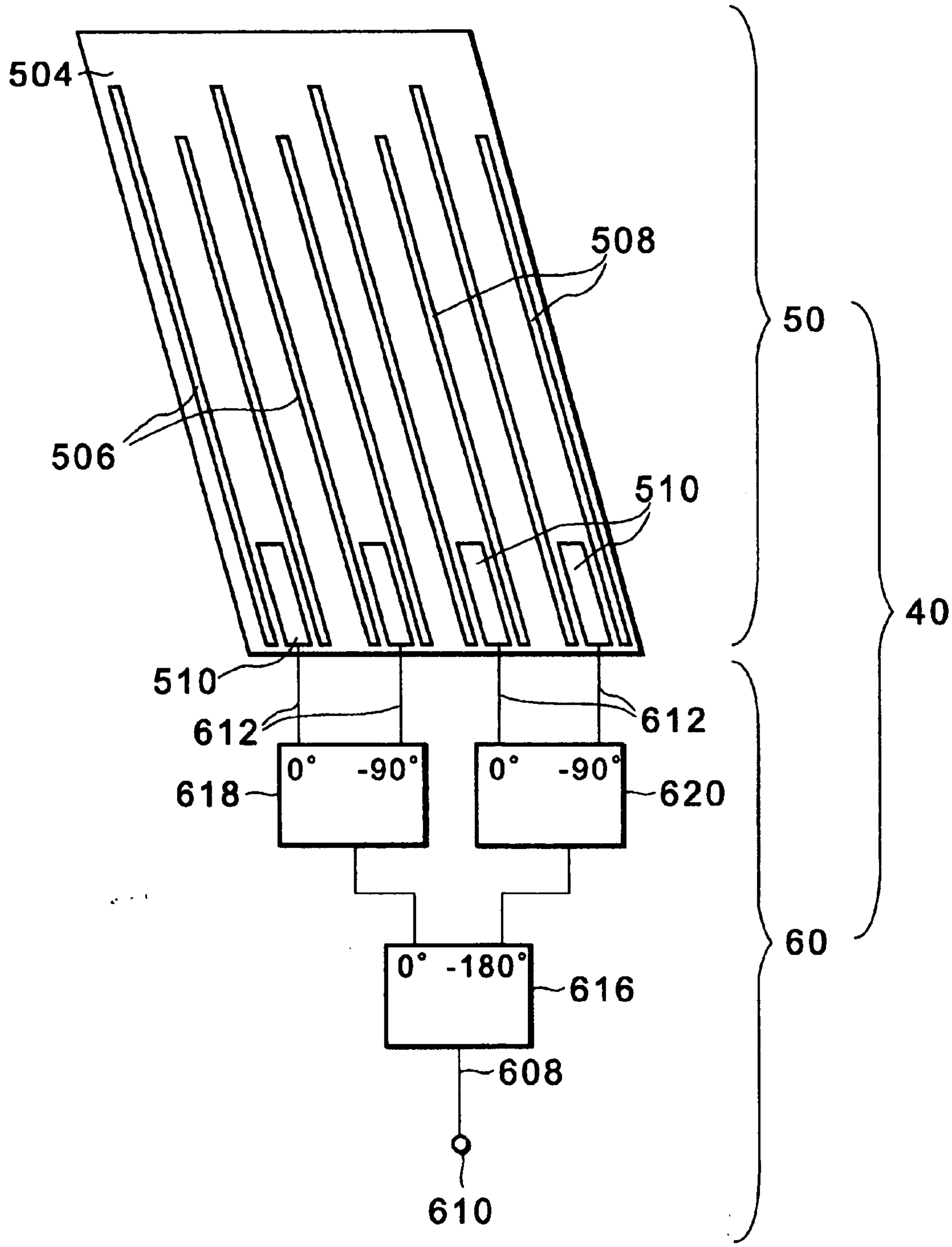
504
508
50
506
510
40
510
612
612
618
0°
-90°
0°
-90°
620
0°
-180°
616
608
60
610

Fig.2

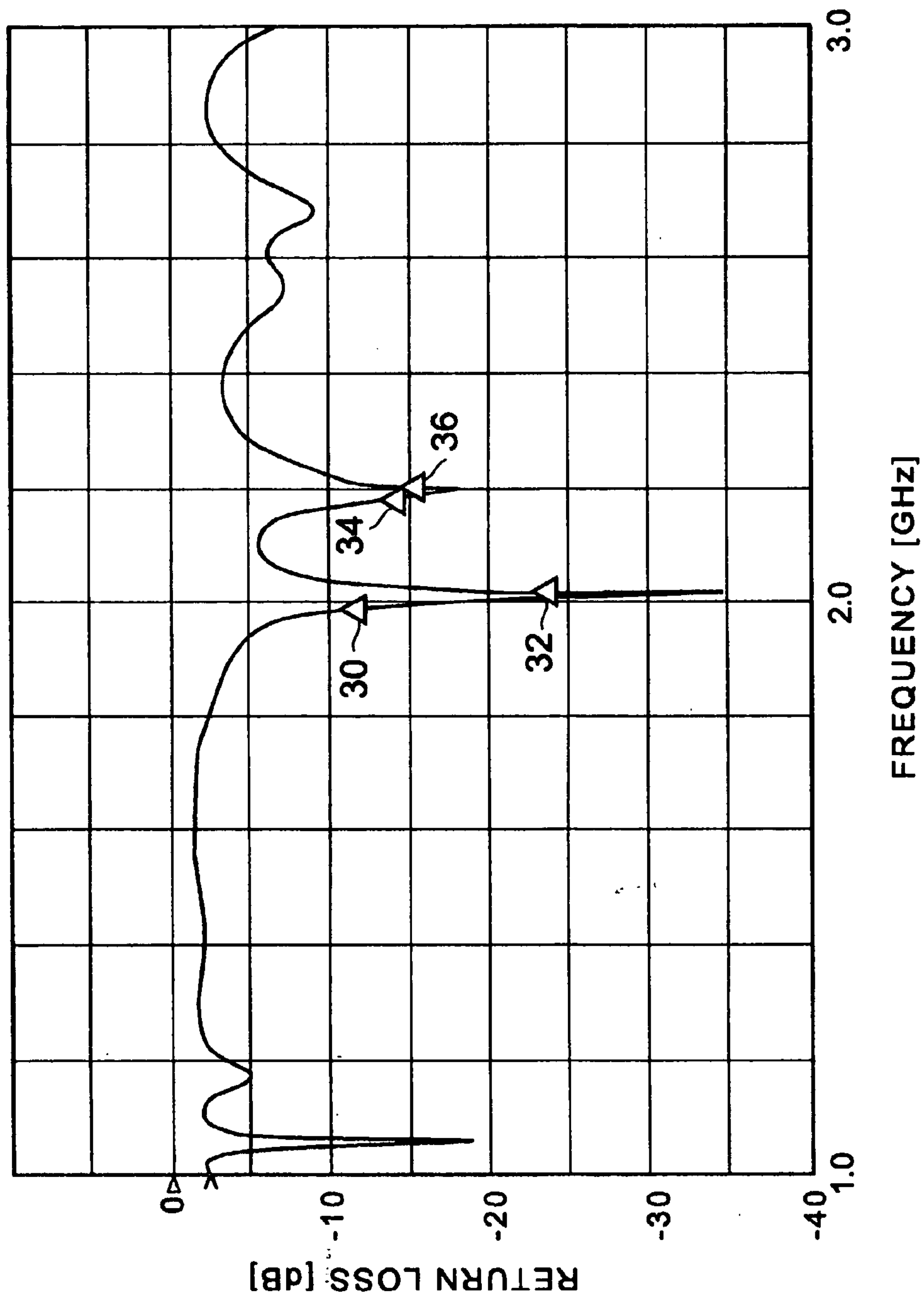

Fig.3

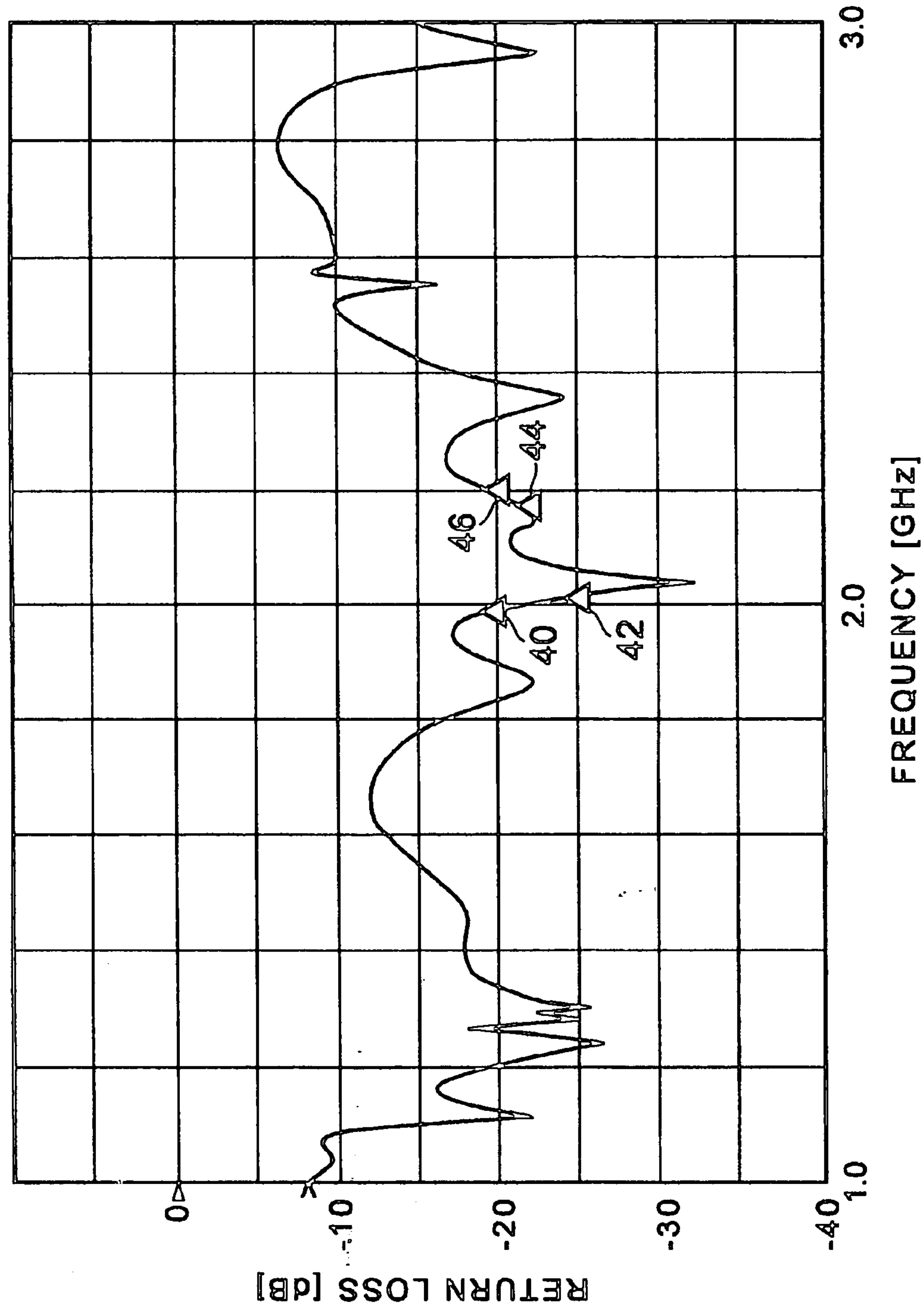

Fig. 4

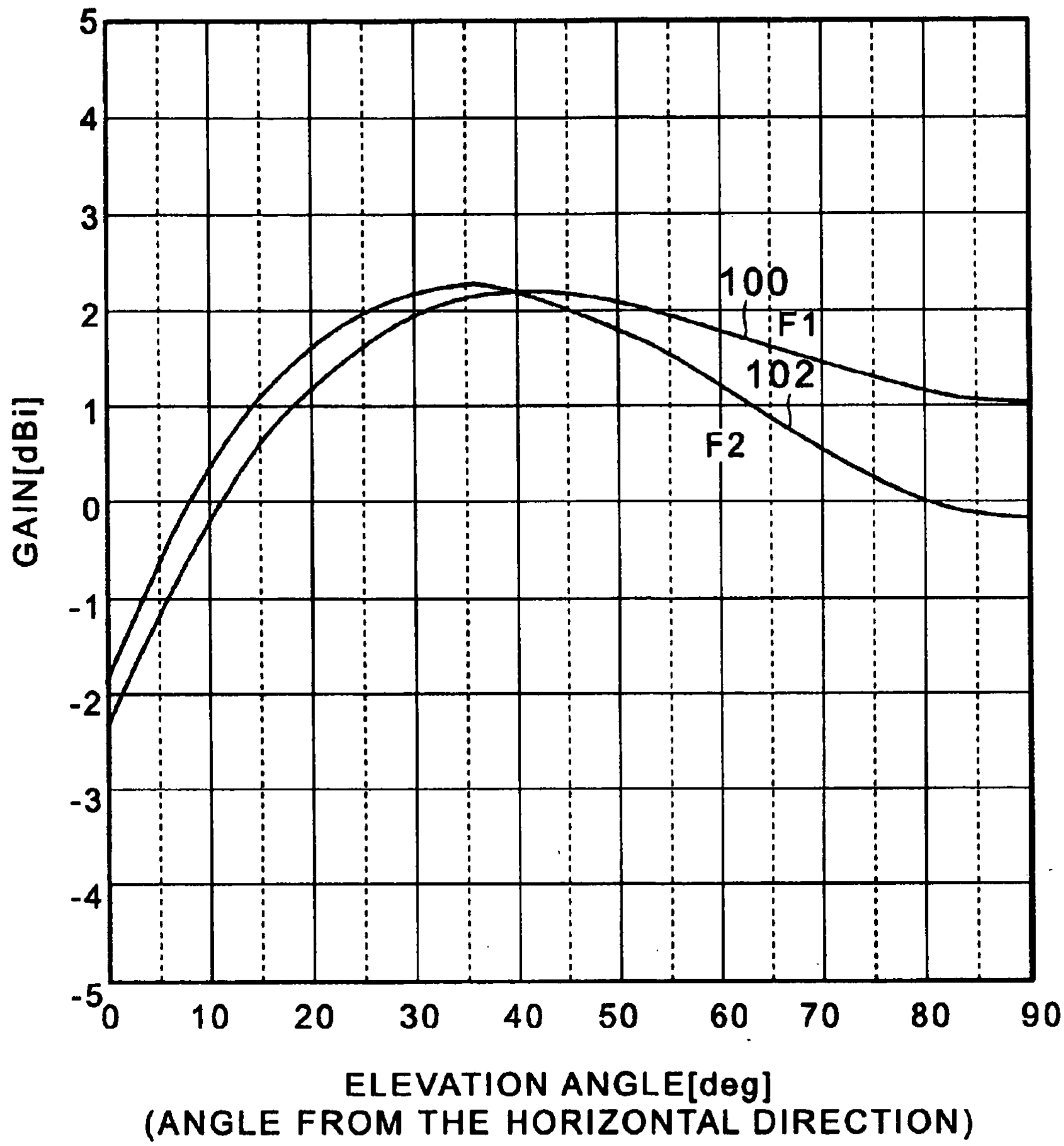
5
4
3
2
1
0
-1
-2
-3
-4
-5
GAIN[dBi]
0
10
20
30
40
50
60
70
80
90
100
F1
102
F2
ELEVATION ANGLE[deg]
(ANGLE FROM THE HORIZONTAL DIRECTION)

Fig.5

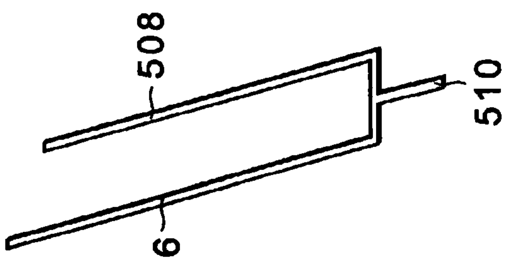

Fig.6E

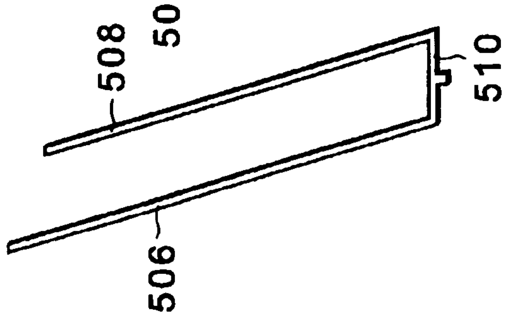

Fig.6D

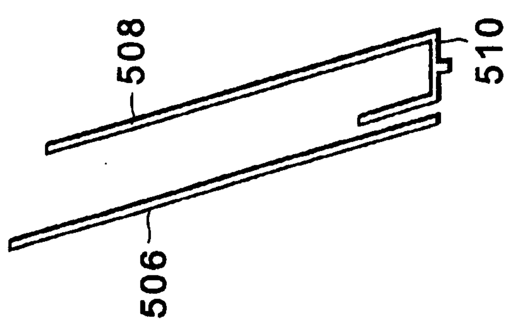

Fig.6C

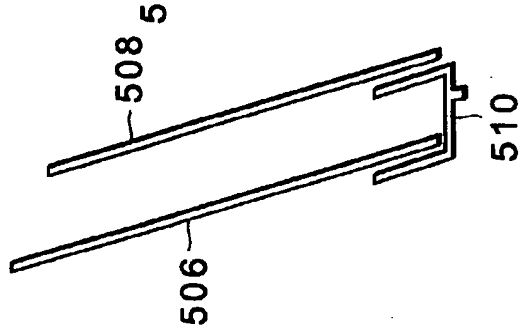

Fig.6B

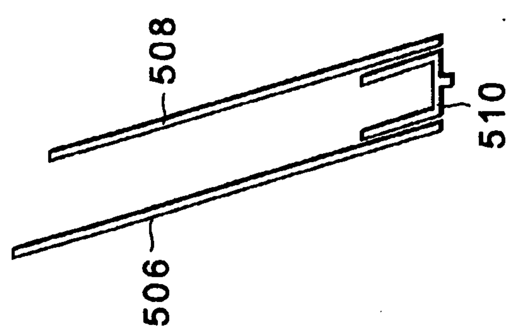

Fig.6A

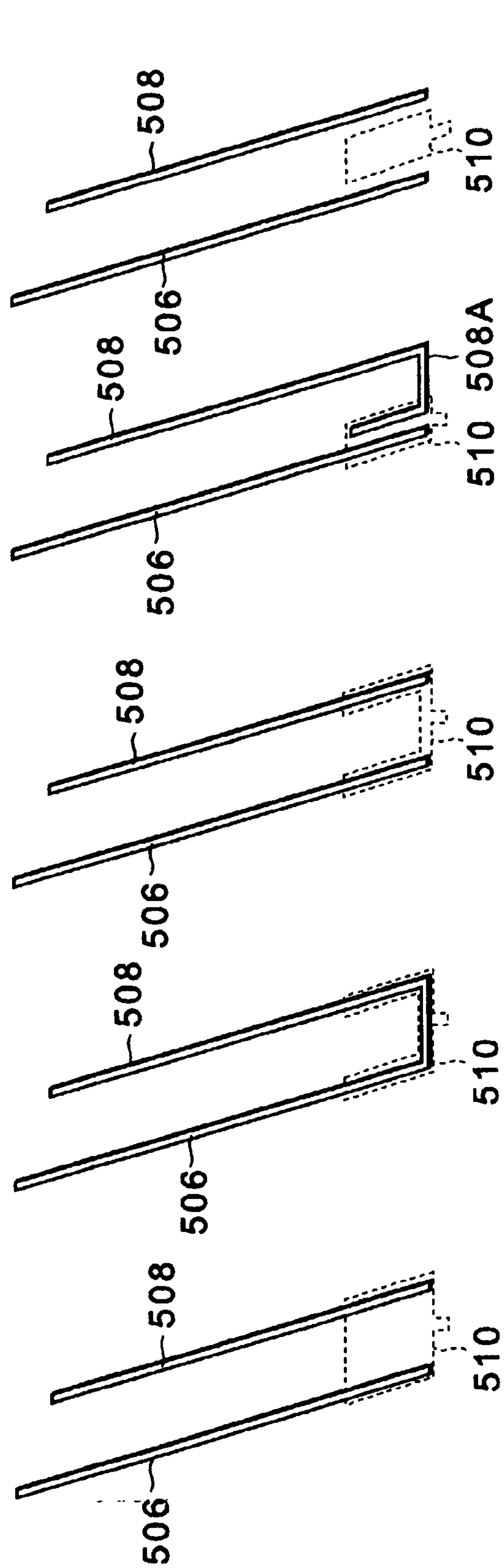

Fig.7A Fig.7B Fig.7C Fig.7D Fig.7E

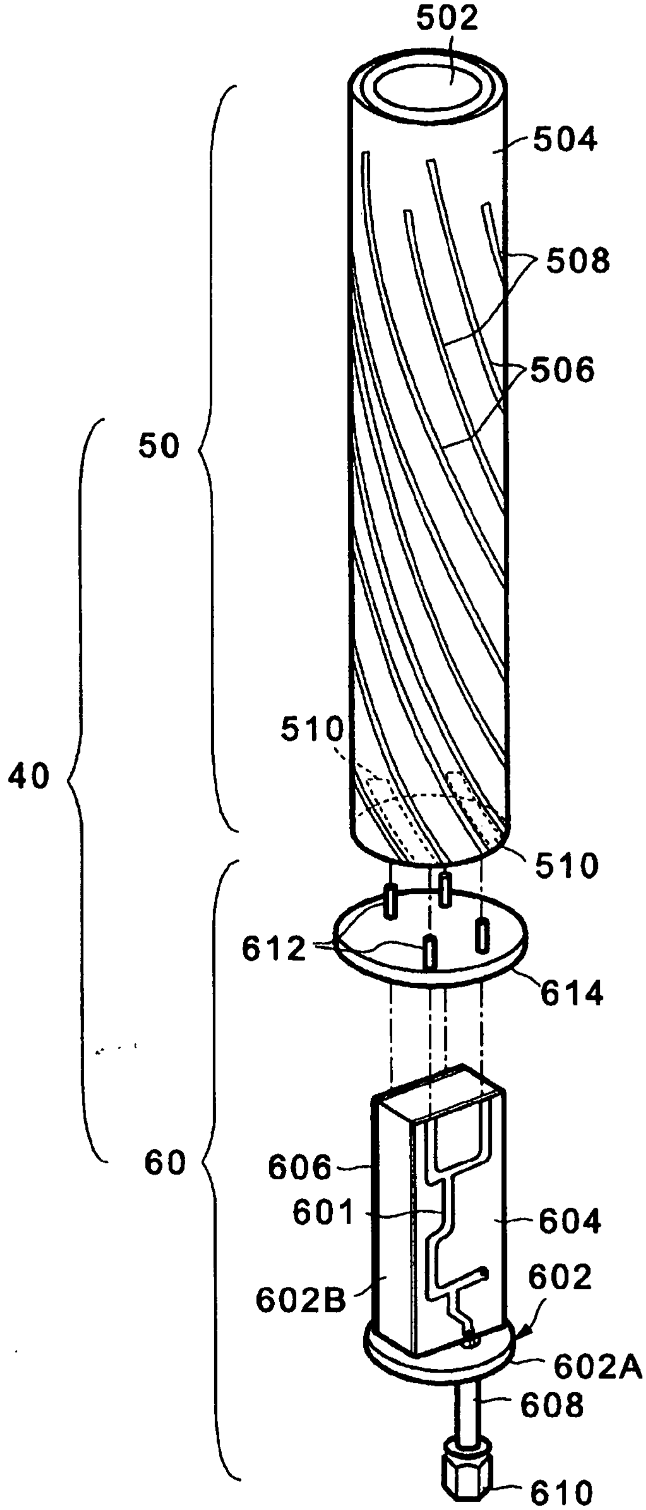
502
504
508
506
50
40
510
510
612
614
60
606
601
604
602B
602
602A
608
610

Fig.8

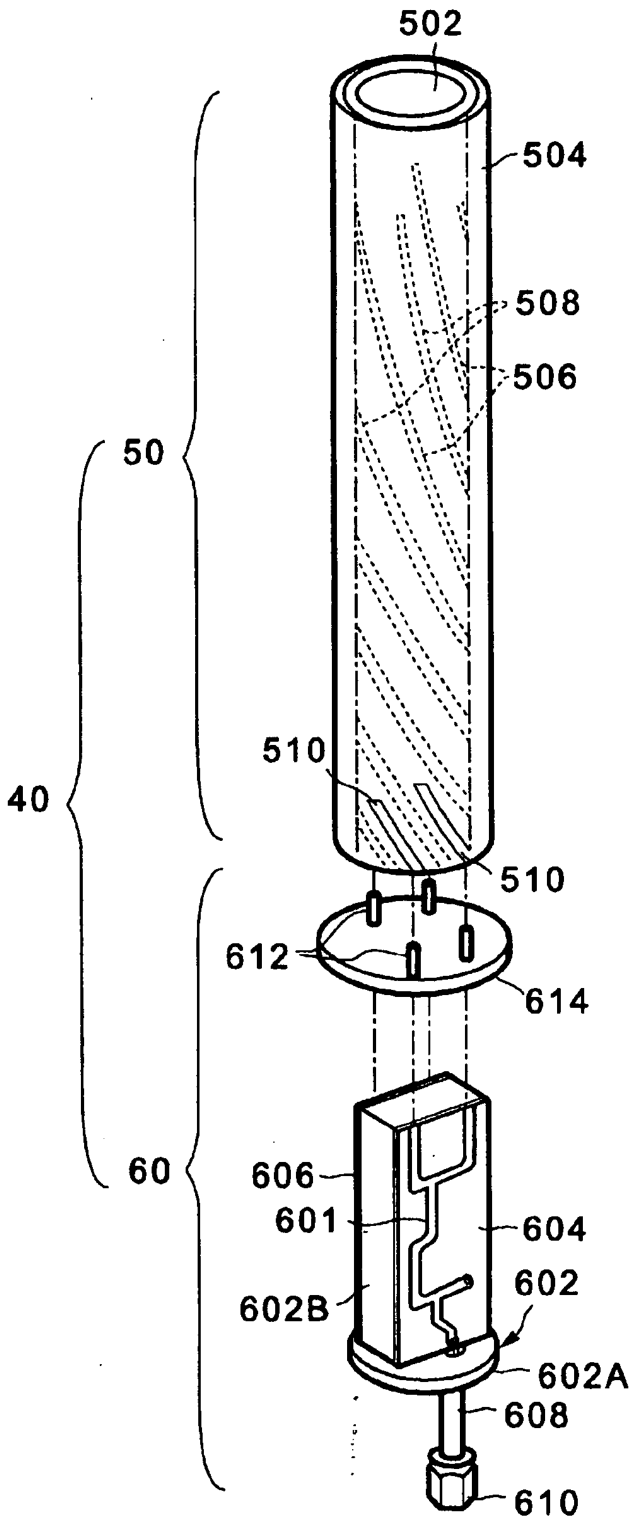
502
504
508
506
50
40
510
510
612
614
60
606
601
604
602
602B
602A
608
610

Fig.9

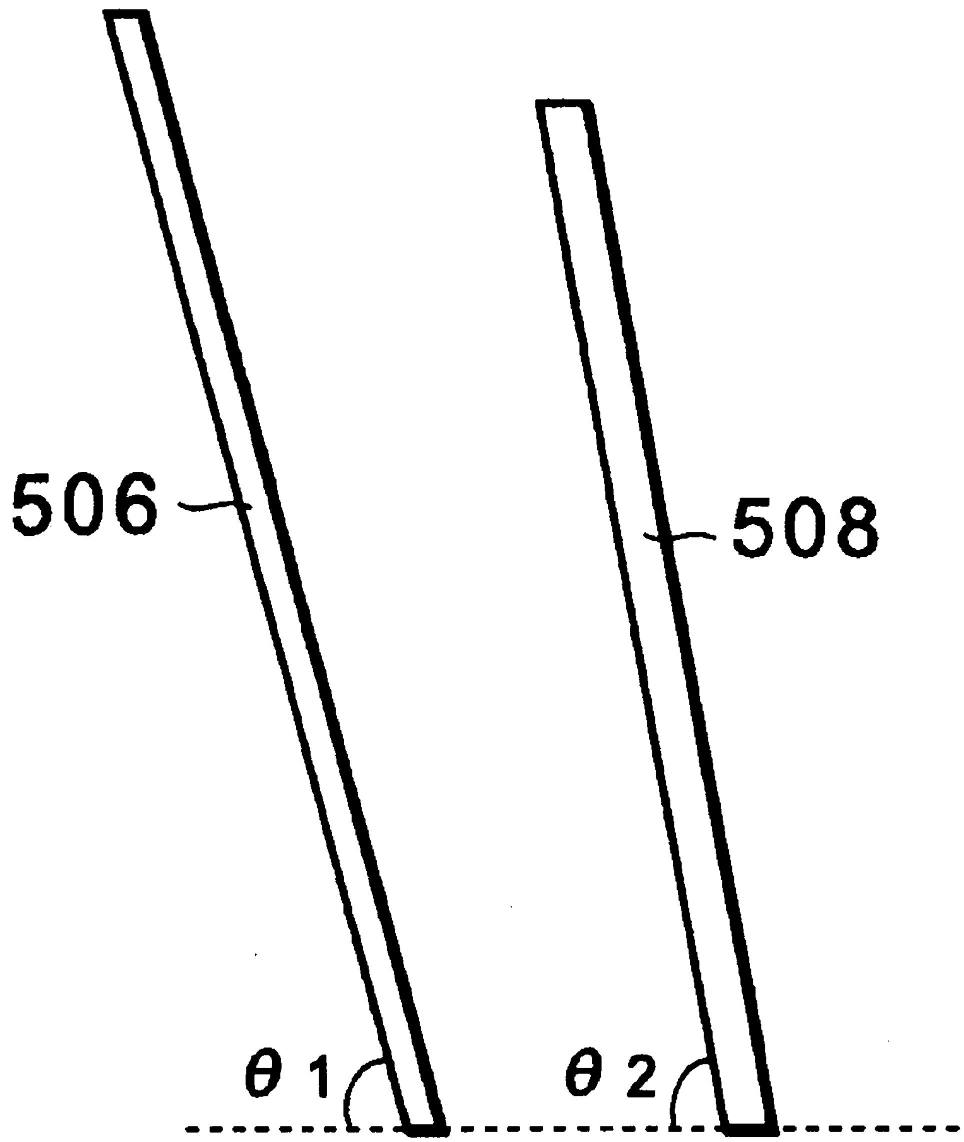

Fig.10

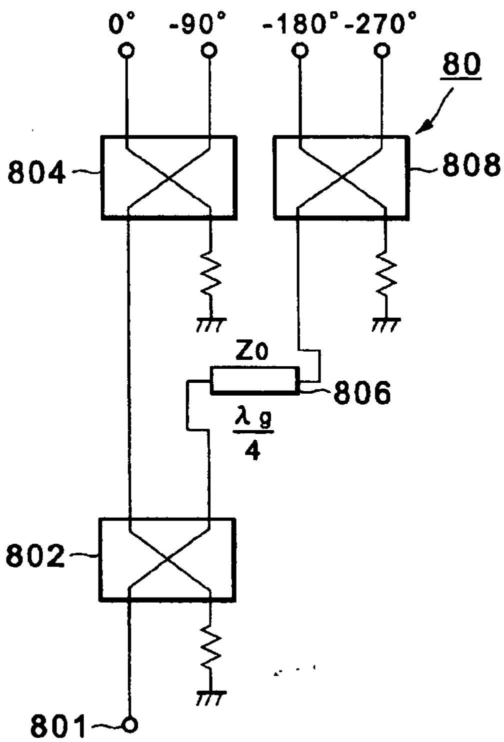

Fig.11A

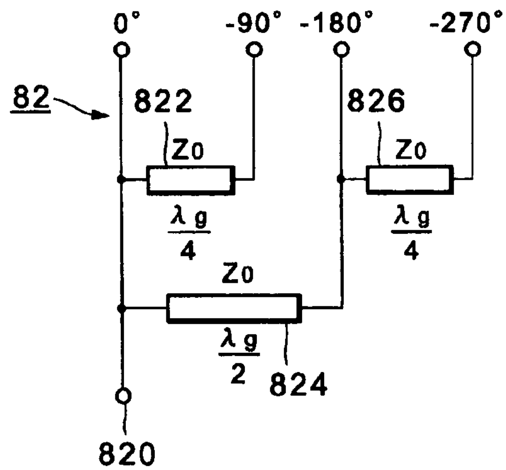

Fig.11B

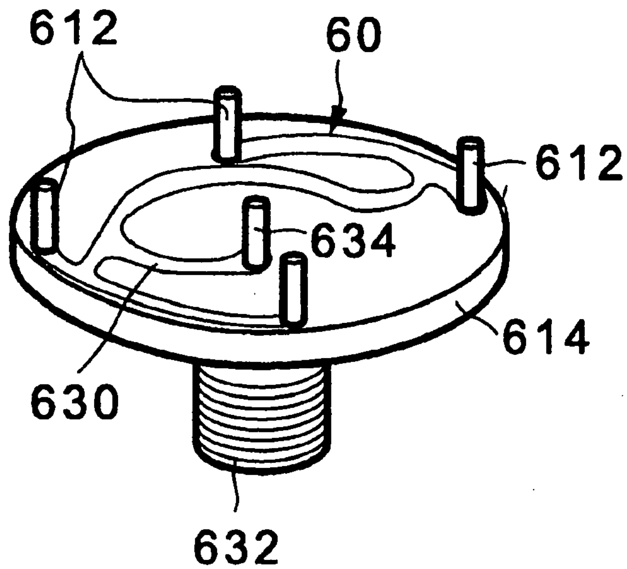

Fig.12

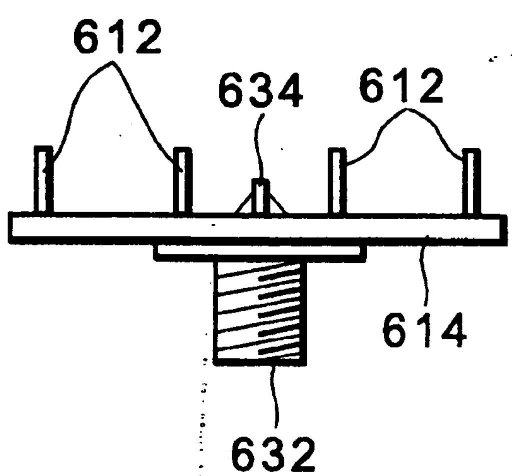

Fig.13

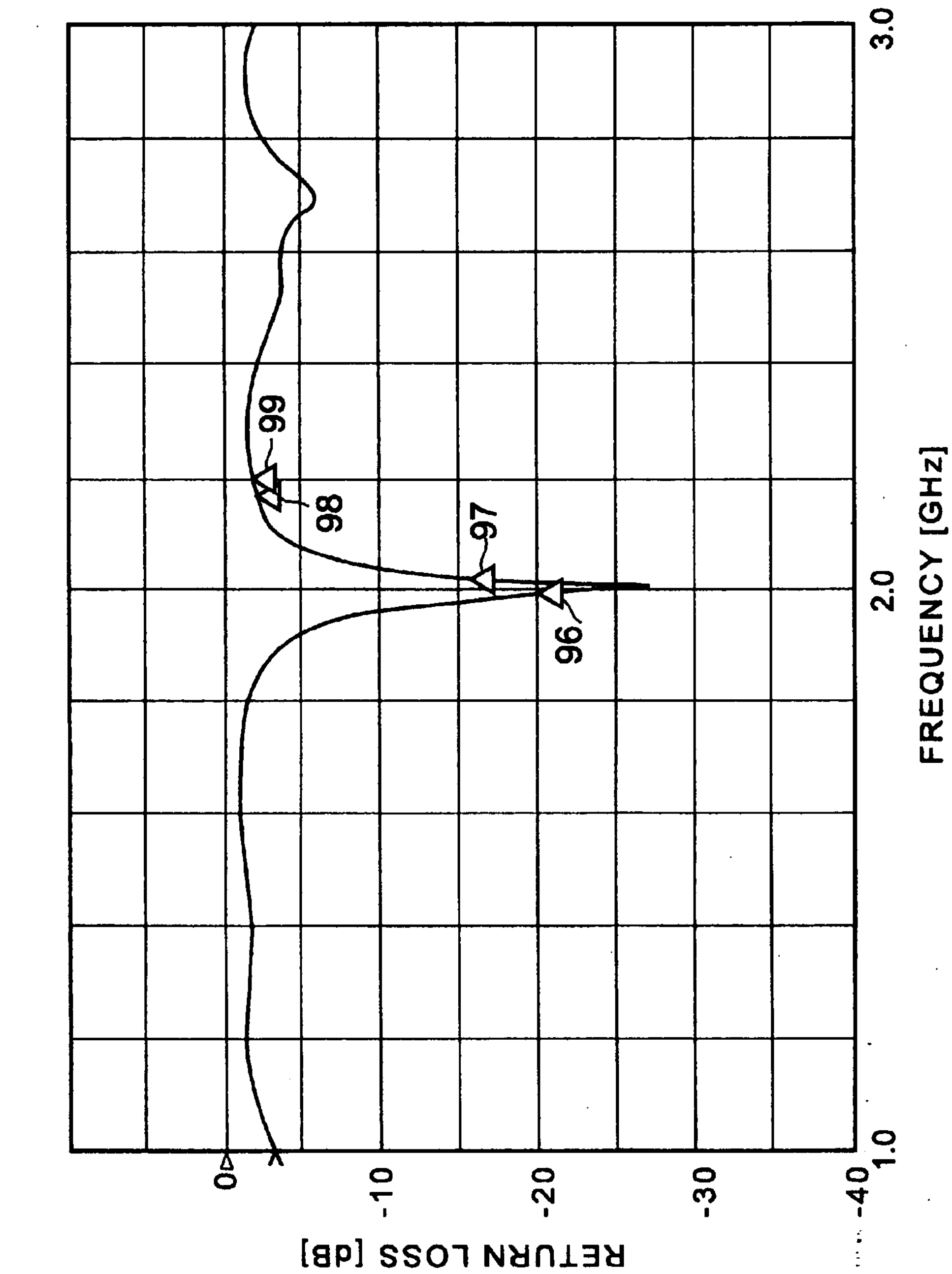

Fig.14
PRIOR ART

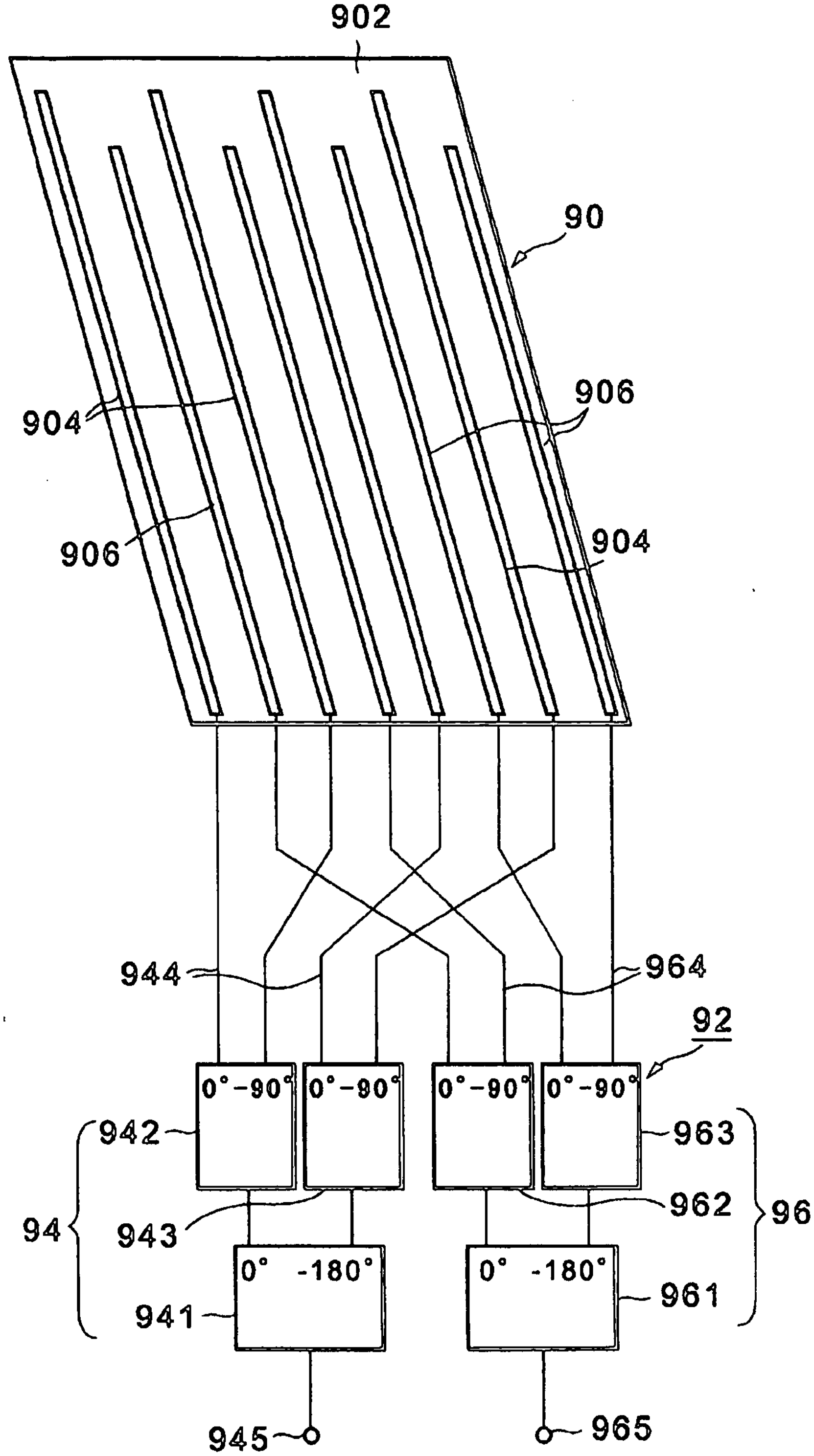

Fig.15
PRIOR ART

METHOD OF PRODUCING A HELICAL ANTENNA AND THE HELICAL ANTENNA APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a helical antenna used as an antenna for a mobile terminal in a mobile radio communication system or the like using a mobile satellite and to a method for producing the helical antenna.

2. Description of the Related Art

A mobile radio communication system using the mobile satellite in general uses a frequency band of 1.985 to 2.015 GHz as a transmission frequency band and a frequency band of 2.17 to 2.2 GHz as a reception frequency band.

In transmission and reception between the mobile satellite and a mobile station, therefore, an antenna having a frequency characteristic capable of effectively performing transmission and reception with a low return loss in a frequency band of about 30 MHz is required.

And a small-sized and lightweight antenna is necessary as an antenna for a mobile terminal.

Thus a helical antenna is used, but in case that such an antenna is made small-sized in axial length and in diameter, its transmission frequency band results in being narrow.

For example, a 4-wire wound helical antenna of about ¼ to ¾ wavelengths in axial length and of about 0.1 wavelength in diameter can cover only such a very narrow frequency band as 1 to 2% of a frequency band to be used.

Due to this, such an antenna as this is unsuitable for an antenna using two different frequency bands, for example, a frequency band of 1.985 to 2.015 GHz and a frequency band of 2.17 to 2.2 GHz like an antenna used in a mobile radio communication system using a mobile satellite.

FIG. **14** is a characteristic diagram showing a relation between frequency and return loss in case that a helical antenna adjusted to a frequency band of 1.985 to 2.015 GHz is used in both frequency bands of 1.985 to 2.015 GHz and 2.17 to 2.2 GHz.

In FIG. **14**, a Δ-mark **96** indicates a return loss at a frequency of 1.985 GHz and a Δ-mark **97** indicates a return loss at a frequency of 2.015 GHz.

And a Δ-mark **98** indicates a return loss at a frequency of 2.17 GHz and a Δ-mark **99** indicates a return loss at a frequency of 2.2 GHz.

As clearly known from FIG. **14**, this antenna can cover transmission and reception in a frequency band of 1.985 to 2.015 GHz, but cannot cover transmission and reception in a frequency band of 2.17 to 2.2 GHz.

FIG. **15** is a structural diagram showing a conventional helical antenna capable of covering the above-mentioned two frequency bands and a feeder circuit of it.

In FIG. **15**, an 8-wire wound antenna body **90** forming the helical antenna is flatly unrolled to be shown.

An 8-wire wound helical antenna capable of covering two frequency bands is formed by winding this antenna body **90** around the outer circumferential surface of a cylindrical body, not illustrated, made of a dielectric material of polycarbonate or the like.

The antenna body **90** is composed of a film **902** formed in the shape of a parallelogram out of a dielectric sheet made of polyimide or the like, first antenna elements **904** composed of conductive wires which extend on one surface of this film **902** in the long-side direction of said film **902** at a specified pitch angle and are arranged in parallel with one another at specified intervals in the short-side direction of said film **902**, and second antenna elements **906** shorter than the first antenna elements **904**.

The first antenna elements **904** and the second antenna elements **906** are arranged alternately with each other in the short-side direction of the film **902** in a state where their lower ends are arranged in a line.

In this case the first antenna elements **904** are adjusted in length to a frequency band of 1.985 to 2.015 GHz and the second antenna elements **906** are adjusted in length to a frequency band of 2.17 to 2.2 GHz.

The feeder circuit **92** is composed of a feeder system **94** of a first frequency band **F1** (of 1.985 to 2.015 GHz) and a feeder system **96** of a second frequency band **F2** (of 2.17 to 2.2 GHz).

The feeder system **94** of the first frequency band **F1** is composed of a dividing/synthesizing circuit **941** which divides a high-frequency signal into two high-frequency signals being different by 180 degrees in phase from each other or synthesizes two high-frequency signals being different by 180 degrees in phase from each other into a high-frequency signal, a dividing/synthesizing circuit **942** which divides one high-frequency signal obtained by division performed by this dividing/synthesizing circuit **941** into two high-frequency signals (of 0 degree and −90 degrees) being different by 90 degrees in phase from each other to feed them to the antenna body **90** or synthesizes two high-frequency signals (of 0 degree and −90 degrees) being different by 90 degrees in phase from each other given from the antenna body **90** into a high-frequency signal, and a dividing/synthesizing circuit **943** which divides the other high-frequency power obtained by division performed by the dividing/synthesizing circuit **941** into two high-frequency signals (of −180 degrees and −270 degrees) being different by 90 degrees in phase from each other to feed them to the antenna body **90** or synthesizes two high-frequency signals (of −180 degrees and −270 degrees) being different by 90 degrees in phase from each other given from the antenna body **90** into a high-frequency signal.

Each of the input/output terminals of the dividing/synthesizing circuits **942** and **943** is connected with each of the first antenna elements **904** of the antenna body **90** through a coupling wire **944**.

Number **945** indicates a connecting terminal to a transmission/reception system of the feeder system **94** of the first frequency band **F1**.

The feeder system **96** of the second frequency band **F2** is composed of a dividing/synthesizing circuit **961** which divides a high-frequency signal into two high-frequency signals being different by 180 degrees in phase from each other or synthesizes two high-frequency signals being different by 180 degrees in phase from each other into a high-frequency signal, a dividing/synthesizing circuit **962** which divides one high-frequency signal obtained by division performed by this dividing/synthesizing circuit **961** into two high-frequency signals (of 0 degree and −90 degrees) being different by 90 degrees in phase from each other to feed them to the antenna body **90** or synthesizes two high-frequency signals (of 0 degree and −90 degrees) being different by 90 degrees in phase from each other given from the antenna body **90** into a high-frequency signal, and a dividing/synthesizing circuit **963** which divides the other high-frequency signal obtained by division performed by the dividing/synthesizing circuit **961** into two high-frequency signals (of −180 degrees and −270 degrees) being different

by 90 degrees in phase from each other to feed them to the antenna body **90** or synthesizes two high-frequency signals (of −180 degrees and −270 degrees) being different by 90 degrees in phase from each other given from the antenna body **90** into a high-frequency signal.

Each of the input/output terminals of the dividing/synthesizing circuits **962** and **963** is connected with each of the second antenna elements **906** of the antenna body **90** through a coupling wire **964**.

Number **965** indicates a connecting terminal to a transmission/reception system of the feeder system **96** of the second frequency band **F2**.

In a conventional helical antenna composed as described above, at the time of transmission, when a high-frequency signal of the first frequency band **F1** is supplied from the transmission system to the terminal **945** of the feeder system **94**, this high-frequency signal is divided by the dividing/synthesizing circuits **941**, **942** and **943** into four high-frequency signals respectively having phase differences of 0, −90, −180 and −270 degrees to be fed to the respective first antenna elements **904** of the antenna body **90**, and is radiated as radio-waves.

And when a high-frequency signal of the second frequency band **F2** is supplied from the transmission system to the terminal **965** of the feeder system **96**, this high-frequency signal is divided by the dividing/synthesizing circuits **961**, **962** and **963** into four high-frequency signals respectively having phase differences of 0, −90, −180 and 270 degrees to be fed to the respective second antenna elements **905** of the antenna body **90**, and is radiated as radio-waves.

On the other hand, among radio-waves receiving at the helical antenna, the radio-waves in the first frequency band **F1** are caught by the first antenna elements **904** of the antenna body **90**, and high-frequency powers generated in the first antenna elements **904** are synthesized in sequence by the dividing/synthesizing circuits **943**, **942** and **941** and are supplied to the reception system through the terminal **945**.

And among radio-waves receiving at the helical antenna, the radio-waves in the second frequency band **F2** are caught by the second antenna elements **906** of the antenna body **90**, and high-frequency powers generated in the second antenna elements **906** are synthesized in sequence by the dividing/synthesizing circuits **963**, **962** and **961** and are supplied to the reception system through the terminal **965**.

However, a conventional helical antenna has a structure where two sets of antenna elements, one of which sets comprises four conductive wires adjusted in length correspondingly to one of the two frequency bands and the other of which sets comprises four conductive wires adjusted in length correspondingly to the other of the two frequency band, are combined and these sets of antenna elements are provided with the respective feeder systems. As clearly known from FIG. **13** also, in order to cover the two frequency bands, six dividing/synthesizing circuits are needed in addition to two feeder connectors corresponding to the number of feeder systems and eight connecting points for the respective conductive wires of the helical antenna.

Therefore, since such feeder circuits can be mounted only two-dimensionally on a printed circuit board, the conventional helical antenna has some problems that the printed circuit board and the feeder circuit portion become large-sized, complicated and expensive.

And it is very difficult also to arrange eight connecting pins or the like for connecting respectively the conductive wires of the helical antenna and the dividing/synthesizing circuits with each other closely to the supporting board of the helical antenna.

SUMMARY OF THE INVENTION

The present invention has been performed in order to solve such a problem as described above, and an object of the present invention is to provide a helical antenna capable of covering a plurality of frequency bands and using common feeder systems for antenna elements adjusted to the respective frequency bands and provide a method for manufacturing the helical antenna.

In order to attain the above-mentioned object, the present invention is characterized by a helical antenna covering a plurality of different frequency bands, comprising;

- a single cylindrical body made of a dielectric material having a specified diameter and a specified length corresponding to wavelengths of said frequency bands,
- a plurality of antenna elements corresponding to the respective frequency bands, said antenna elements being formed by arranging alternately with one another a plurality of conductive wires adjusted in length to wavelengths of the respective frequency bands helically at a specified pitch angle with a spacing between each other on the outer circumferential surface of said cylindrical body in the circumferential direction of said cylindrical body, and a plurality of coupling lines each of which is electromagnetically coupled with said conductive wires, which are adjacent to each other and different in length from each other, of said respective antenna elements formed on said cylindrical body.

According to the present invention, it is possible to cover a plurality of frequency bands and use common feeder systems for antenna elements adjusted to the respective frequency bands.

And the present invention is characterized by a method for manufacturing a helical antenna covering a plurality of different frequency bands, comprising;

- a step of providing a cylindrical body made of a dielectric material having a specified diameter and a specified length corresponding to wavelengths of said frequency bands,
- a step of providing a dielectric sheet large enough to cover the outer circumferential surface of said cylindrical body,
- a step of forming a plurality of antenna elements by providing a plurality of conductive wires adjusted in length to wavelengths of the respective frequency bands with a spacing between each other and forming a plurality of coupling lines for electromagnetically coupling with each other one-side ends of said antenna elements which are adjacent to each other and are different in length from each other, and
- a step of winding said dielectric sheet which said plurality of antenna elements and said plurality of coupling lines are formed on around the outer circumferential surface of said cylindrical body.

According to the present invention, it is possible to form a plurality of antenna elements and a plurality of coupling lines in the same process and easily manufacture said helical antenna.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exploded view in perspective of a helical antenna according to an embodiment of the present invention.

FIG. 2 is a structural Figure showing a state where an antenna body according to the embodiment of the present invention is flatly unrolled and a feeder circuit connected with said antenna.

FIG. 3 is a graph showing a return loss characteristic obtained by seeing the antenna side from the electromagnetic coupling line side in the embodiment of the present invention.

FIG. 4 is a graph showing a return loss characteristic obtained by seeing the antenna side from the connector side in the embodiment of the present invention.

FIG. 5 is a graph showing an emission pattern characteristic of a high-frequency signal radiated from the helical antenna in the embodiment of the present invention.

FIGS. 6A to 6E are explanatory figures showing other embodiments of a coupling line structure for coupling a feeder circuit to antenna elements according to the present invention.

FIGS. 7A to 7E are explanatory figures showing further other embodiments of a coupling line structure for coupling a feeder circuit to antenna elements according to the present invention.

FIG. 8 is an exploded view in perspective of a helical antenna according to other embodiment of the present invention.

FIG. 9 is an exploded view in perspective of a helical antenna according to further other embodiment of the present invention.

FIG. 10 is a structural figure showing another embodiment of an antenna element according to the present invention.

FIGS. 11A and 11B are embodiment showing a feeder circuit according to the present invention.

FIG. 12 is a perspective view showing other embodiment showing a feeder circuit according to the present invention on a supporting plate of a helical antenna.

FIG. 13 is a side view of FIG. 12.

FIG. 14 is a characteristic diagram showing a relation between frequency and return loss of a helical antenna according to the prior art.

FIG. 15 is a structural Figure showing a helical antenna and its feeder circuit according to the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A helical antenna according to the present invention is described together with a method for manufacturing the helical antenna with reference to FIGS. 1 to 13 in the following.

FIG. 1 is an exploded view in perspective of a helical antenna of an embodiment according to the present invention, and FIG. 2 is a structural Figure showing a state where an antenna body is flatly unrolled and a feeder circuit connected with said antenna.

In FIGS. 1 and 2, a helical antenna 40 is provided with an antenna body 50 composed so that it can cover two frequency bands of a first frequency band F1 (of 1.985 to 2.015 GHz) and a second frequency band F2 (of 2.17 to 2.2 GHz), and a feeder circuit 60 commonly used by this antenna body 50.

As shown in FIGS. 1 and 2, said antenna body 50 is provided with a cylindrical body 502 having a diameter of about 8% of wavelength of the first frequency band F1 or the second frequency band F2 and a specified length and being made of a dielectric material such as polycarbonate, FRP or the like, and a dielectric sheet 504 formed out of polyimide or the like in the shape of a parallelogram, said dielectric sheet being wound around the outer circumferential surface of this cylindrical body 502.

On one surface of said dielectric sheet 504, as shown in FIG. 2, four first antenna elements 506 extending in the long-side direction of the dielectric sheet 502 at a pitch angle of about 69 degrees and four second antenna elements 508 shorter than said first antenna element 506 are arranged in parallel and alternately with one another at certain intervals in the short-side direction of the dielectric sheet 504 and the lower ends of the first antenna elements 506 and the second antenna elements 508 are arranged in a line.

The length of said first antenna elements 506 is about ¾ of wavelength of the first frequency band F1 and the length of said second antenna elements 508 is about ¾ of wavelength of the second frequency band F2.

Four coupling lines 510 each of which is electromagnetically coupled with one of the first antenna elements 506 and one of the second antenna elements 508 being adjacent to each other are formed at portions of the dielectric sheet 504 corresponding to the lower ends of the first antenna elements 506 and the second antenna elements 508.

The length of said coupling line 510 is about 14% of wavelength of the first frequency band F1 or the second frequency band F2.

The spacing between the coupling line 510 and the first antenna element 506 or the second antenna element 508 is about 1% of wavelength of the first frequency band F1 or the second frequency band F2.

The reason why the lengths of the first and second antenna elements 506 and 508 and the length of the coupling line 510 are set as said values is that a good impedance matching characteristics in the first and second frequency bands F1 and F2 and a wide radiation pattern characteristic (a wide directivity) in the vertex direction of the helical antenna can be obtained.

The first antenna elements 506, the second antenna elements 508 and the coupling lines 510 are formed at the same time in the same process by forming a copper foil layer in advance on the surface of the dielectric sheet 504 and etching this copper foil layer into an antenna element pattern shown in FIG. 2.

In FIG. 1, the feeder circuit 60 is provided with a base 602 made of aluminum having a disk 602A and a flat plate 602B provided perpendicularly to the upper surface of the disk 602A, two printed circuit boards 604 and 606 which are attached to both faces of the flat plate 602B and on which dividing/synthesizing circuit 601 composed of 3 dB hybrid circuits, microstrip lines and the like are mounted, a feeder coaxial cable 608 which is joined with the downside of the disk 602A of the base 602 and is connected with the printed circuit boards 604 and 606, and a connector 610 which is provided on the head end of the coaxial cable 608 and is to be connected with an unillustrated transmission and reception system.

Additionally, it is provided with a supporting plate 614 made of an electrically insulating material which plate supports the antenna body 50 and has four connecting pins 612 for connecting the coupling lines 510 of the antenna body 60 with the printed circuit boards 604 and 606.

These connecting pins 612 penetrate through the supporting plate 614 to project upward and downward, and the projecting ends of the connecting pins 612 are respectively

connected by soldering to the coupling lines **510** of the antenna body **60** and the feeder terminals of the printed circuit boards **604** and **606**.

In FIG. **2**, the feeder circuit **60** is composed of a dividing/synthesizing circuit **616** which divides a high-frequency power of the first frequency band F1 (of 1.985 to 2.015 GHz) and the second frequency band F2 (of 2.17 to 2.2 GHz) into two high-frequency signals being different by 180 degrees in phase from each other or synthesizes two high-frequency signals being different by 180 degrees in phase from each other into a high-frequency signal, a dividing/synthesizing circuit **618** which divides one high-frequency signal obtained by division performed by this dividing/synthesizing circuit **616** into two high-frequency signals (of 0 degree and 90 degrees) being different by 90 degrees in phase from each other to feed them to the antenna body **50** or synthesizes two high-frequency signals (of 0 degree and −90 degrees) being different by 90 degrees in phase from each other given from the antenna body **50** into a high-frequency signal, and a dividing/synthesizing circuit **620** which divides the other high-frequency signal obtained by division performed by the dividing/synthesizing circuit **616** into two high-frequency signals (of −180 degrees and −270 degrees) being different by 90 degrees in phase from each other to feed them to the antenna body **50** or synthesizes two high-frequency signals (of −180 degrees and −270 degrees) being different by 90 degrees in phase from each other given from the antenna body **50** into a high-frequency signal.

Next, operation of a helical antenna composed as described above is described with reference to FIG. **2**.

When a high-frequency signal of the first frequency band F1 (of 1.985 to 2.015 GHz) or the second frequency band F2 (of 2.17 to 2.2 GHz) is fed to the helical antenna through the connector **610**, this high-frequency signal is transmitted through the cable **608** and is distributed by the dividing/synthesizing circuits **616**, **618** and **620** mounted on the printed circuit boards **604** and **606** to the four connecting pins **612**.

At this time the high-frequency signals distributed to the four connecting pins **612** are equal in amplitude to one another and are different by 90 degrees in phase from one another so as to be 0 degree, −90 degrees, −180 degrees and −270 degrees.

The high-frequency signals distributed into four are fed through the four electromagnetic coupling lines **510** to the antenna elements **506** and **508**.

Hereupon, the high-frequency signals of the first frequency band F1 and the second frequency band F2 operate in different manners from each other.

That is to say, the high-frequency signal of the lower first frequency band F1 is transmitted to the longer first antenna elements **506**, and radiates a high-frequency signal in its transmission process.

In a 4-wire type helical antenna of this kind, since a frequency characteristic of return loss is very narrow, its impedance is not matched with respect to the shorter second antenna elements **508** and the high-frequency signal is little transmitted to it.

For the lower first frequency band F1, therefore, only the longer first antenna elements **506** operate in such a manner as connected.

Similarly, the high-frequency signal of the higher second frequency band F2 is transmitted to only the shorter second antenna elements **508**, and is little transmitted to the first antenna elements **506**.

Among radio-waves received at the helical antenna **40**, the radio-wave of the first frequency band F1 is caught by the first antenna elements **506** of the antenna body **50**, and high-frequency signals generated in the first antenna elements **506** are synthesized in sequence by the dividing/synthesizing circuits **618**, **620** and **616** and are fed through the cable **608** and the connector **610** to the reception system.

Among radio-waves receiving at the helical antenna **40**, the radio-wave of the second frequency band F2 is caught by the second antenna elements **508** of the antenna body **50**, and high-frequency signals generated in the second antenna elements **508** are synthesized in sequence by the dividing/synthesizing circuits **618**, **620** and **616** and are fed through the cable **608** and the connector **610** to the reception system.

FIG. **3** shows a return loss characteristic obtained by seeing the first and second antenna elements **506** and **508** sides from the electromagnetic coupling lines **510** side.

In FIG. **3**, a Δ-mark **30** indicates a return loss at a frequency of 1.985 GHz and a Δ-mark **32** indicates a return loss at a frequency of 2.015 GHz.

And a Δ-mark **34** indicates a return loss at a frequency of 2.17 GHz and a Δ-mark **36** indicates a return loss at a frequency of 2.2 GHz.

As clearly known from FIG. **3**, this antenna can cover transmission and reception in a frequency band of 1.985 to 2.015 GHz, and can also cover transmission and reception in a frequency band of 1.985 to 2.015 GHz.

FIG. **4** shows a return loss characteristic obtained by seeing the first and second antenna elements **506** and **508** sides from the connector **610** side.

In FIG. **4**, a Δ-mark **40** indicates a return loss at a frequency of 1.985 GHz and a Δ-mark **42** indicates a return loss at a frequency of 2.015 GHz.

And a Δ-mark **44** indicates a return loss at a frequency of 2.17 GHz and a Δ-mark **46** indicates a return loss at a frequency of 2.2 GHz.

FIG. **5** is a graph showing a radiation pattern characteristic of a high-frequency signal radiated from a helical antenna according to this embodiment, in which the abscissa shows an angle from the horizontal plane (elevation angle) and the ordinate shows the intensity of radio-waves.

In FIG. **5**, curve **100** shows a radiation pattern characteristic of the first frequency band F1 and curve **102** shows a radiation pattern characteristic of the second frequency band F2.

As clearly known from FIG. **5**, the helical antenna of this embodiment can cover the first frequency band F1 and the second frequency band F2. According to this embodiment as described above, it is possible to cover the first frequency band F1 and the second frequency band F2 and use the power feeding circuit **60** commonly to the first and second antenna elements **506** and **508** adjusted to the respective frequency bands by electromagnetically coupling one-side ends adjacent to each other of the sets of the first and second antenna elements **506** and **508** by means of the coupling lines **510**.

Thus, the helical antenna can do with one feeder circuit **60**, and also can do with one cable and one connector, and so the feeder circuit portion can be made small in size.

And according to the embodiment of the present invention, since the first and second antenna elements **506** and **508** and the coupling lines **510** can be formed at the same time by etching a copper foil on the surface of the dielectric sheet **504**, such a helical antenna composed as described above can be easily manufactured.

FIGS. 6A to 6E are explanatory figures showing other embodiments of the structure of a coupling line 510 for coupling a feeder circuit 60 to first and second antenna elements according to the present invention.

FIG. 6A shows a structure which forms a coupling line 510 for coupling a first antenna element 506 and a second antenna element 508 to a feeder circuit 60 into a U shape having a spacing smaller than the spacing between the first and second antenna elements 506 and 508. One branch of this U-shaped coupling line 510 is electromagnetically coupled to one end portion of the first antenna element 506 with a gap between them, and the other branch is electromagnetically coupled to one end portion of the second antenna element 508 with a gap between them.

FIG. 6B shows a structure which forms a coupling line 510 for coupling a first antenna element 506 and a second antenna element 508 to a feeder circuit 60 into a U shape having a spacing equal to the spacing between the first and second antenna elements 506 and 508. One branch of this U-shaped coupling line 510 is electromagnetically coupled to one end portion of the first antenna element 506 with a gap between them, and the other branch is electromagnetically coupled to one end portion of the second antenna element 508 with a gap between them.

FIG. 6C shows a structure which forms a coupling line 510 for coupling a first antenna element 506 and a second antenna element 508 to a feeder circuit 60 into an L shape. One end of this coupling line 510 is joined directly to one end of the second antenna element 508, and the other end of this coupling line 510 is electromagnetically coupled to one end portion of the first antenna element 506 with a gap between them.

FIG. 6D shows a structure which forms a coupling line 510 for coupling a first antenna element 506 and a second antenna element 508 to a feeder circuit 60 so as to be electrically directly connected with one-side ends of the first and second antenna elements 506 and 508.

FIG. 6E shows a structure which is the same as the structure of FIG. 6D except for having a long coupling line at the center of the coupling line 510.

The coupling lines in these embodiments can be formed on the same surface as the surface of the dielectric sheet on which the antenna elements are formed. Therefore, these embodiments have an advantage providing an easy frequency adjustment by cutting a pattern of the elements or the line.

FIGS. 7A to 7E are explanatory figures showing further embodiments of the structure of a coupling line 510 for coupling first and second antenna elements to a feeder circuit 60 according to the present invention.

FIG. 7A shows a structure which forms a coupling line 510 for coupling a first antenna element 506 and a second antenna element 508 to a feeder circuit 60 on the surface opposite to the surface of a dielectric sheet on which the first and second antenna elements 506 and 508 are formed, so as to be opposite to the first and second antenna elements 506 and 508, as shown by a dashed line, and thereby couples the coupling line 510 electromagnetically with the first and second antenna elements 506 and 508.

FIG. 7B shows a structure which joins with each other one-side ends of a first antenna element 506 and a second antenna element 508, forms a coupling line 510 for coupling the first antenna element 506 and the second antenna element 508 to a feeder circuit 60 into a U shape having a spacing equal to the spacing between the first and second antenna elements 506 and 508 and on the surface opposite to the surface of a dielectric sheet on which the first and second antenna elements 506 and 508 are formed, so as to be opposite to the first and second antenna elements 506 and 508, as shown by a dashed line, and thereby couples the coupling line 510 electromagnetically with the first and second antenna elements 506 and 508.

FIG. 7C shows a structure which forms a coupling line 510 for coupling a first antenna element 506 and a second antenna element 508 to a feeder circuit 60 into a U shape having a spacing equal to the spacing between the first and second antenna elements 506 and 508, as shown by a dashed line, and on the surface opposite to the surface of a dielectric sheet on which the first and second antenna elements 506 and 508 are formed, so as to be opposite to the first and second antenna elements 506 and 508, and thereby couples the coupling line 510 electromagnetically with the first and second antenna elements 506 and 508.

FIG. 7D shows a structure which forms one end portion 508A of the second antenna element 508 into an L shape and makes the one end portion 508A close to one end of the first antenna element 506, and forms a coupling line 510 for coupling the first and second antenna elements 506 and 508 to a feeder circuit, as shown by a dashed line, on the surface opposite to the surface of a dielectric sheet on which the first and second antenna elements 506 and 508 are formed, so as to be opposite to the one end portion of the first antenna element 506 and the L-shaped one end portion 508A, and couples the coupling line 510 electromagnetically with the first and second antenna elements 506 and 508.

FIG. 7E shows the same structure as the structure shown in FIG. 7A except for that the coupling line 510 is adjacent to the antenna elements 506 and 508.

FIG. 8 shows other embodiment of the helical antenna. FIG. 8 is the same structure as the structure shown in FIG. 1 except for that the coupling line structure is the structure shown in FIG. 7E.

FIG. 9 shows further other embodiment of the helical antenna. FIG. 9 is the same structure as the structure shown in FIG. 1 except for that the coupling lines 510 are formed on the outer surface of the cylindrical body 502 and the antenna elements 508, 506 are formed on the inner surface of the cylindrical body 502.

FIG. 10 is explanatory figure showing other embodiment of the structure of first antenna elements 506 and second antenna elements 508 according to the present invention. The first antenna elements 506 and the second antenna elements 508 are arranged in parallel at same fixed pitch angle as shown in FIGS. 1, 2, 6A to 6E and 7A to 7E. However, the first antenna elements 506 and the second antenna elements 508 in FIG. 10 are not arranged in parallel at the same pitch angle. As shown in FIG. 10, the first antenna elements 506 have an incline angle of $\theta 1$ degree from a horizontal line (the edge of the dielectric sheet 504). The second antenna elements 508 have an incline angle of $\theta 2$ degree from the horizontal line. The $\theta 1$ and $\theta 2$ are selected so that the first antenna elements 506 and the second antenna elements 508 do not cross respectively. A pitch angle of the helical antenna, formed by winding this antenna body with these antenna elements around the cylindrical body, is changeable by changing the $\theta 1$ and $\theta 2$. Therefore, when a beam tilt between the transmission frequency band and the reception frequency band is occurred in case of a parallel arrangement of the antenna elements, the beam tilt of the helical antenna is compensated by changing the $\theta 1$ and $\theta 2$.

FIGS. 11A and 11B are compositional diagrams showing embodiments of a feeder circuit 60 shown in FIG. 2.

In FIG. 11A, a dividing/synthesizing circuit **80** forming a feeder circuit **60** is composed of a first 3-dB hybrid circuit **802** to be connected to a feeder terminal **801**, a second 3-dB hybrid circuit **804** which is connected to one output terminal of this hybrid circuit **802** and divides a high-frequency signal into two high-frequency signals (of 0 degree and −90 degrees) or synthesizes them into a high-frequency signal, and a third 3-dB hybrid circuit **808** which is connected through a ¼-wavelength line **806** of impedance Z0 to the other output terminal of the first 3-dB hybrid circuit **802** and divides a high-frequency signal into two high-frequency signals (of −180 degrees and −270 degrees) or synthesizes them into a high-frequency signal.

In FIG. 11B, a dividing/synthesizing circuit **82** forming a feeder circuit **60** is composed of a ¼-wavelength line **822** of impedance Z0 which is connected with a feeder terminal **820** and divides a high-frequency signal into two high-frequency signals of 0 degree and −90 degrees in phase or synthesizes them into a high-frequency signal, a ½-wavelength λg line **824** of impedance Z0 which is connected to the feeder terminal **820** and divides a high-frequency signal into two high-frequency signals of 0 degree and −180 degrees in phase or synthesizes them into a high-frequency signal, and a ¼-wavelength λg line **826** of impedance Z0 which divides a high-frequency signal given from the ½-wavelength line **824** into two high-frequency signals of −180 degrees and −270 degrees in phase or synthesizes them into a high-frequency signal.

Also in case of incorporating such a dividing/synthesizing circuit **80** or **82** into a helical antenna **40**, the same action and effect as the case shown in FIG. 2 can be obtained.

Next, with reference to FIGS. 12 and 13, other embodiment of the present invention in case of forming a feeder circuit **60** on a supporting plate of a helical antenna is described.

In FIGS. 12 and 13, a feeder circuit **60** formed by combining a plurality of microstrip lines **630** of fractions of wavelength of a frequency band to be used is formed on the surface of a supporting plate **614** of a helical antenna.

As shown in FIG. 1, the microstrip lines **630** of the feeder circuit **60** are connected to a plurality of connecting pins **612** being provided on and projecting from the places of the supporting plate **614**, 'said places being opposite to the respective coupling lines **510** of the antenna body **50**.

And a connector **632** for feeding power to the feeder circuit **60** is fixed on the middle of the reverse surface of the supporting plate **614**, and a connecting pin **634** which penetrates through the supporting plate **614** from the connector **632** to project from the surface of the supporting plate **614** is connected to the microstrip line **630** of the feeder circuit **60**.

The microstrip lines having a pattern shown in FIG. 12 are formed by adopting a method of forming in advance a copper foil on the surface of the supporting plate **614** and etching this copper foil as a method for forming said microstrip lines **630** of the feeder circuit **60**.

And as another method it is possible also to form the microstrip lines **630** of a pattern shown in FIG. 10 on the surface of the supporting plate **614** by means of printing.

In a helical antenna having such a composition as described above, the base **602**, the printed circuit boards **604** and **606**, and the cable **608** shown in FIG. 1 can be omitted, the length of the whole helical antenna can be shortened, and the number of components of the helical antenna can be reduced, and thereby the helical antenna can be easily made smaller in size and lower in cost.

In the above-mentioned embodiments, although a helical antenna covering two frequency bands of a first frequency band F1 and a second frequency band F2 in a mobile radio communication system using a satellite, the present invention is not limited to this, but can be applied also to a helical antenna covering three or more frequency bands to be used in a similar way to said case of applying the invention to two frequency bands although the number of kinds of antenna elements being different in length from one another is increased correspondingly to the frequency bands to be used.

As described above, according to a helical antenna of the present invention, it is possible to cover a plurality of frequency bands and commonly use a feeder circuit for antenna elements corresponding to the respective frequency bands by coupling the respective sets of antenna elements corresponding to the respective wavelengths electromagnetically with the feeder circuit by means of coupling lines.

By this, the helical antenna can do with one feeder circuit and can do also with one cable and one connector, and therefore can have the feeder circuit portion made smaller in size.

And according to a helical antenna of the present invention, it is possible to easily reduce the number of components of the helical antenna and make the helical antenna smaller in size and lower in cost.

And according to a helical antenna manufacturing method of the present invention, it is possible to easily manufacture such a helical antenna as described above.

What is claimed is:

1. A helical antenna covering a plurality of different frequency bands, comprising;
   - a cylindrical body;
   - a plurality of antenna elements that have a plurality of different lengths that are based on the wavelengths of the plurality of different frequency bands and that are arranged alternately in sets of the antenna elements at a specified pitch angle on the surface of said cylindrical body;
   - a plurality of coupling lines that are each capacitively coupled with each of the antenna elements in a respective one of said sets of antenna elements; and
   - a feeder circuit that is connected to all of said plurality of coupling lines and that has a common input/output port for conveying all signals of different frequency bands that are received and transmitted by said plurality of antenna elements.

2. The helical antenna as defined in claim **1**, wherein a dielectric sheet is wound around the outer circumferential surface of said cylindrical body, and said plurality of antenna elements and said plurality of coupling lines are formed on said dielectric sheet.

3. The helical antenna as defined in claim **1**, wherein the length of said coupling lines is set according to the wavelength of one of the plurality of different frequency bands.

4. The helical antenna as defined in claim **1**, wherein said coupling lines are formed on the same surface as the surface of the dielectric sheet on which said antenna elements are formed.

5. The helical antenna as defined in claim **1**, wherein said coupling lines are formed on the opposite surface to the surface of the dielectric sheet on which said antenna elements are formed.

6. The helical antenna as defined in claim 1, wherein said cylindrical body including said antenna elements is supported by a supporting plate, and said feeder circuit and said coupling lines are connected with each other through connecting pins provided on said supporting plate.

7. The helical antenna as defined in claim 6, wherein said supporting plate is disposed at an end in the longitudinal direction of said cylindrical body.

8. The helical antenna as defined in claim 7, wherein a printed circuit board is disposed on the surface opposite to the surface of said supporting plate facing said cylindrical body and said feeder circuit is mounted on said printed circuit board.

9. The helical antenna as defined in claim 8, wherein said connecting pins penetrating through said supporting plate are provided across between the cylindrical body and the printed circuit board.

10. The helical antenna as defined in claim 8, wherein said printed circuit board is supported by a base.

11. The helical antenna as defined in claim 10, wherein a cable for feeding signal to said feeder circuit is provided on said base.

12. The helical antenna as defined in claim 11, wherein said cable is provided with a connector.

13. The helical antenna as defined in claim 1, wherein said feeder circuit is composed of a plurality of dividing/synthesizing circuits each of which divides a high-frequency signal into high-frequency signals having specified phases corresponding to the number of conductive wires forming said antenna elements or synthesizes the high-frequency signals.

14. The helical antenna as defined in claim 13, wherein said dividing/synthesizing circuit is composed by combining a hybrid circuit and a microstrip line corresponding to a fraction of wavelength of a frequency band to be used.

15. The helical antenna as defined in claim 13, wherein said dividing/synthesizing circuit is composed by combining a plurality of microstrip lines each of which corresponds to a fraction of wavelength of a frequency band to be used.

16. The helical antenna as defined in claim 1, wherein said cylindrical body including said antenna-elements is supported by a supporting plate, said feeder circuit is formed on said supporting plate, and said feeder circuit and said coupling lines are connected with each other through said connecting pins provided in the supporting plate.

17. The helical antenna as defined in claim 16, wherein said supporting plate is provided with a connector for feeding signal to said feeder circuit.

18. The helical antenna as defined in claim 16, wherein said feeder circuit is composed by combining a plurality of wavelength lines each of which corresponds to a fraction of wavelength of a frequency band to be used.

19. A method for manufacturing a helical antenna covering a plurality of different frequency bands, comprising the steps of;

- providing a cylindrical body;
- providing a dielectric sheet large enough to cover the surface of said cylindrical body;
- forming on said dielectric sheet a plurality of antenna elements that have a plurality of different lengths that are based on the wavelengths of the plurality of different frequency bands, that are arranged alternately in sets at a specified pitch angle on the surface of said cylindrical body;
- forming a plurality of coupling lines that are each capacitively coupled with each of the antenna elements in a respective one of said sets of said antenna elements;
- winding said dielectric sheet which said plurality of antenna elements and said plurality of coupling lines are formed on around the surface of said cylindrical body; and
- providing a feeder circuit that is connected to all of said plurality of coupling lines and that has a common input/output port for conveying all signals of different frequency bands that are received and transmitted by said plurality of antenna elements.

20. The method for manufacturing a helical antenna as defined in claim 19, wherein said plurality of antenna elements and said plurality of coupling lines are formed on the surface of said dielectric sheet in a state where said dielectric sheet is flatly unrolled.

21. The method for manufacturing a helical antenna as defined in claim 19, wherein said dielectric sheet is formed in the shape of a parallelogram in a state where it is flatly unrolled so that said dielectric sheet can be wound around said cylindrical body at said specified pitch angle.

22. The method for manufacturing a helical antenna as defined in claim 21, wherein said plurality of antenna elements are linearly formed in parallel with the long sides of said parallelogram and with a spacing between each other.

23. The method for manufacturing a helical antenna as defined in claim 19, wherein said dielectric sheet has a copper foil on the surface of it and said plurality of antenna elements and said plurality of coupling lines are formed by etching said copper foil.

24. The method for manufacturing a helical antenna as defined in claim 19, wherein said plurality of antenna elements and said plurality of coupling lines are formed by printing on the surface of said dielectric sheet.

25. A helical antenna covering a plurality of different frequency bands, comprising;

- a cylindrical body;
- a plurality of antenna elements, which have different lengths based on wavelengths of said different frequency bands, arranged alternately in sets at a specified pitch angle on the surface of said cylindrical body;
- a plurality of coupling lines that are each connected directly to each of the antenna elements in a respective one of said sets of antenna elements; and
- a feeder circuit that is connected to all of said plurality of coupling lines and that has a common input/output port for conveying all signals of different frequency bands that are received and transmitted by said plurality of antenna elements.

26. A helical antenna for covering a first frequency and a second frequency that is different from the first frequency, the antenna comprising:

- a cylindrical surface;
- plural first antenna elements on said surface that each have a first length that is a function of a wavelength of the first frequency;
- plural second antenna elements on said surface that each have a second length different from the first length and that is a function of a wavelength of the second frequency;
- plural coupling lines that each are capacitively coupled with one of said first antenna elements and one of said second antenna elements and that each electromagnetically couple a different one of said first antenna ele-

ments to a different one of said second antenna elements; and

a feeder circuit that is connected to all of said plural coupling lines and that has a common input/output port for conveying all signals of the first and second frequencies that are received and transmitted by said first and second antenna elements.

27. The antenna of claim **26**, wherein said coupling lines are spaced from respective ones of said first and second antenna elements by a distance that is a function of a wavelength of one of the first and second frequencies.

28. The antenna of claim **26**, wherein said coupling lines have a length that is a function of one of the first and second frequencies.

29. The antenna of claim **1**, wherein said plurality of antenna elements are arranged at different pitch angles based on said plurality of different frequency bands.

30. The antenna of claim **25**, wherein said plurality of antenna elements are arranged at different pitch angles based on said plurality of different frequency bands.

31. The antenna of claim **26**, wherein said first antenna elements and second antenna elements are arranged in parallel at same pitch angle.

32. The antenna of claim **26**, wherein said first antenna elements and second antenna elements are arranged at different pitch angles.

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